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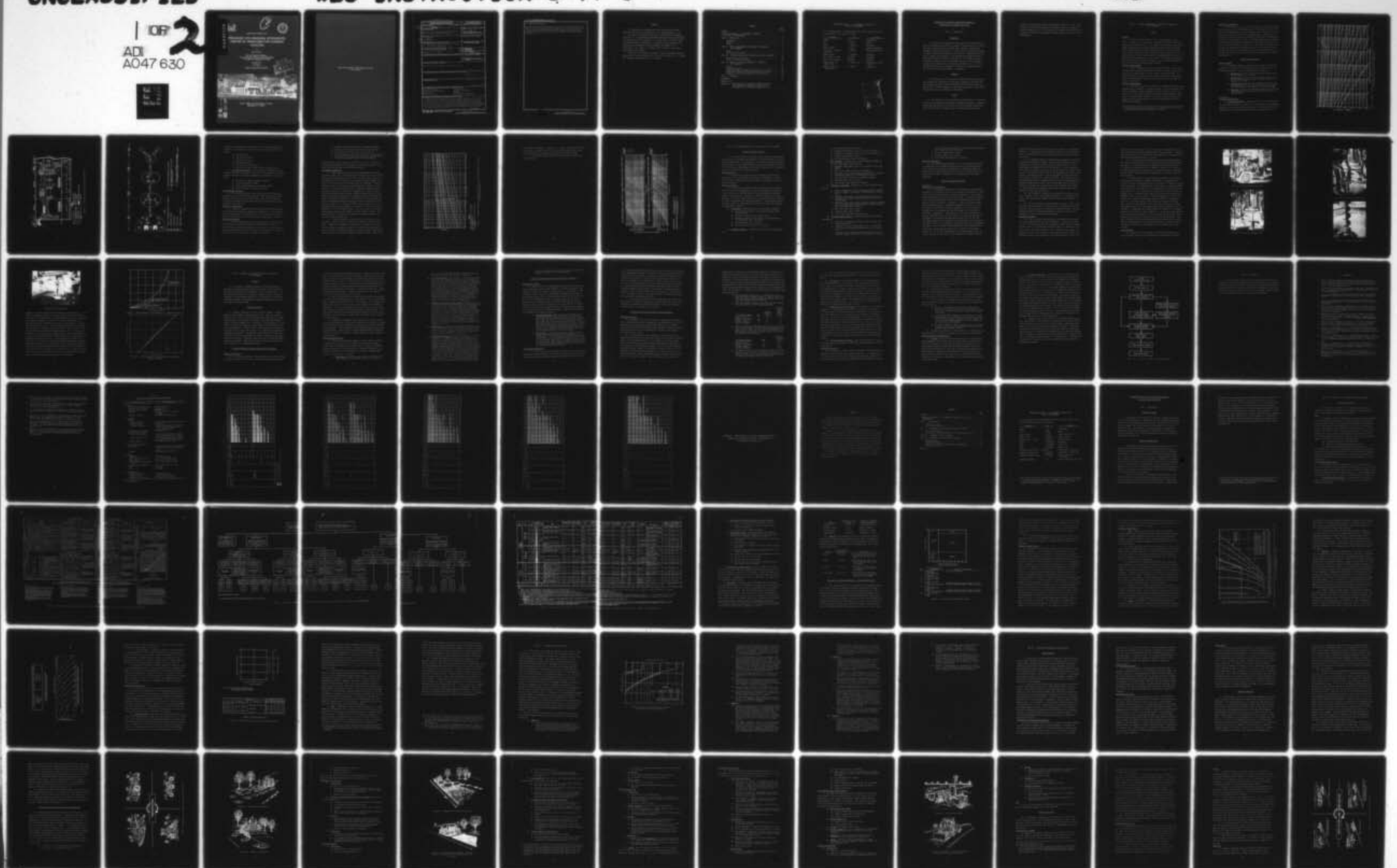

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INSTRUCTION REPORT S-77

PROCEDURE FOR UPGRADING THEATER OF OPERATIONS (T FACILITIES

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study was conducted to develop expedient procedures for assessing the structural and functional adequacy of existing pavement systems in the theater of operations (TO) and to provide guidance for upgrading inadequate or deteriorated facilities to meet operational requirements. This instruction report presents simplified procedures for the evaluation of existing pavements and alternate expedient procedures for upgrading the pavement systems where

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20. ABSTRACT (Continued).

required. The construction procedures and techniques described herein have been validated in prototype pavement structures or in special test sections that were designed, constructed, and traffic tested to validate various construction techniques and procedures for upgrading deteriorated pavement structures.

PREFACE

The investigation reported herein was sponsored by the Headquarters, Office, Chief of Engineers, U. S. Army, Washington, D. C.

The study was conducted by personnel of the Soils and Pavements Laboratory, U. S. Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. J. P. Sale and R. G. Ahlvin, Chief and Assistant Chief, respectively. Personnel actively engaged in the planning and conducting of the investigation were Messrs. R. L. Hutchinson, A. H. Joseph, C. D. Burns, and R. W. Grau. This report was prepared by Mr. Burns.

Directors of WES during the conduct of this investigation and the preparation of this report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurements used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles	1.609344	kilometres
square inches	6.4516	square centimetres
miles (U. S. statute) per hour	1.609344	kilometres per hour
pounds (mass)	0.4535924	kilograms
kips (1000 lb, mass)	453.5924	kilograms
tons (2000 lb, mass)	907.1847	kilograms
pounds (mass) per cubic inch	2.76799×10^4	kilograms per cubic metre
pounds (force) per square inch	6.894757	kilopascals

PROCEDURE FOR UPGRADING DETERIORATED THEATER OF OPERATIONS (TO) PAVEMENT FACILITIES

PART I: INTRODUCTION

Background

1. In any military operation, the problem of providing adequate roads, airfields, and heliports to support a military mission is a major task and is costly in terms of money, time, manpower, construction equipment, and natural resources. Criteria for the planning and design of roads, airbases, and heliports in the theater of operations (TO) are given in detail in Department of the Army Technical Manual TM 5-330.[1] Construction methods are given in TM 5-337.[2] In the planning stage of a military operation, first consideration should be given to making maximum use of existing roads, airfields, and heliports. Some of the existing facilities may be adequate to support the planned missions, and others may require improvements or upgrading.

Purpose

2. The purpose of this study was to develop expedient procedures for assessing the structural and functional adequacy of existing pavement systems based upon visual examination and/or simplified test procedures and to provide guidance for upgrading inadequate or deteriorated facilities to meet the operational requirements.

Scope

3. The objectives of this study were accomplished by a literature review of applicable data pertaining to pavement performance, evaluation procedures, and special test sections that were designed, constructed, and traffic tested to validate various construction techniques and

procedures for upgrading deteriorated pavement structures. This study provides information and guidance for expedient means of evaluation of existing pavements in the TO and alternate procedures and techniques for upgrading deteriorated or inadequate pavement facilities to meet mission requirements.

PART II: DESIGN REQUIREMENTS FOR THEATER OF OPERATIONS (TO) PAVEMENTS

Roads

General

4. Details of road design for the TO are presented in Reference 1 (Chapter 10). The quality of military roads varies considerably based upon many factors. In a combat zone, military urgency almost always dictates use of existing roads and/or rough, hastily prepared roads designed primarily to meet pressing needs. On the other hand, in rear areas, especially in the vicinity of major airfields, ports, and supply installations, an improved net of well-surfaced, fairly high-type roads may be required. In all military road design, consideration must be given to use of stage construction for progressive upgrading of the road to satisfy increased traffic demands.

Geometric requirements

5. Table 1 summarizes the military specifications. These specifications will, under most conditions, provide a combat road, which will meet military requirements and some measure of driving safety. The criteria relating to widths, curves, grades, and similar features are based upon maintaining a traffic volume of 2000 vehicles per day at a speed of 25-35 mph.*

Surfacing requirements

6. Most TO roads will be unsurfaced or surfaced with sand, gravel, crushed rock, or whatever is locally available. Under very urgent conditions, expedient surfacing methods are used to get the traffic over soft soils. Some existing roads may be surfaced with bituminous materials or portland cement concrete. The type of surface required will depend on the type and volume of traffic and the estimated time for mission accomplishment.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

Structural requirements

7. Most paved roads in the TO will consist of a base and subbase course and some type of bituminous surface. The total thickness of the base and pavement depends upon the strength of the subgrade, the design load, and the design service life of the pavement. Thickness design criteria are based on equivalent 18,000-lb, single-axle, dual-wheel load operations, as indicated in Figure 1. Complete procedures for determining the equivalent 18,000-lb, single-axle, dual-wheel load operations are outlined in Reference 1 (Chapter 10). Also given in Reference 1 are criteria for compaction requirements, selection of design California Bearing Ratio (CBR) for select materials, and subbase and base courses. Pavement mix design criteria and construction procedures are discussed in Reference 2.

Airfields and Heliports

General concepts

8. For planning purposes, military areas within a TO are shown graphically in Figure 2 for fixed-wing aircraft and in Figure 3 for rotary-wing aircraft. The areas included are as follows:

- a. Battle area. Sector of the battlefront normally under military control of a brigade.
- b. Forward area. Sector of the TO immediately behind the battle area and normally under military control of a brigade or division.
- c. Support area. Sector of the TO behind the forward area and normally within the Army Corps service areas under military control of the Fighter Air Security Command.
- d. Rear area. Sector of the TO behind the support area and normally within the Army service area or the zone of communications.

Controlling aircraft classification

9. Fixed-wing aircraft. Fixed-wing aircraft are classified in six categories (Reference 1, Chapter 11), which embrace all fixed-wing aircraft in the current military inventory. A controlling aircraft, or combination of controlling aircraft, has been designated for each

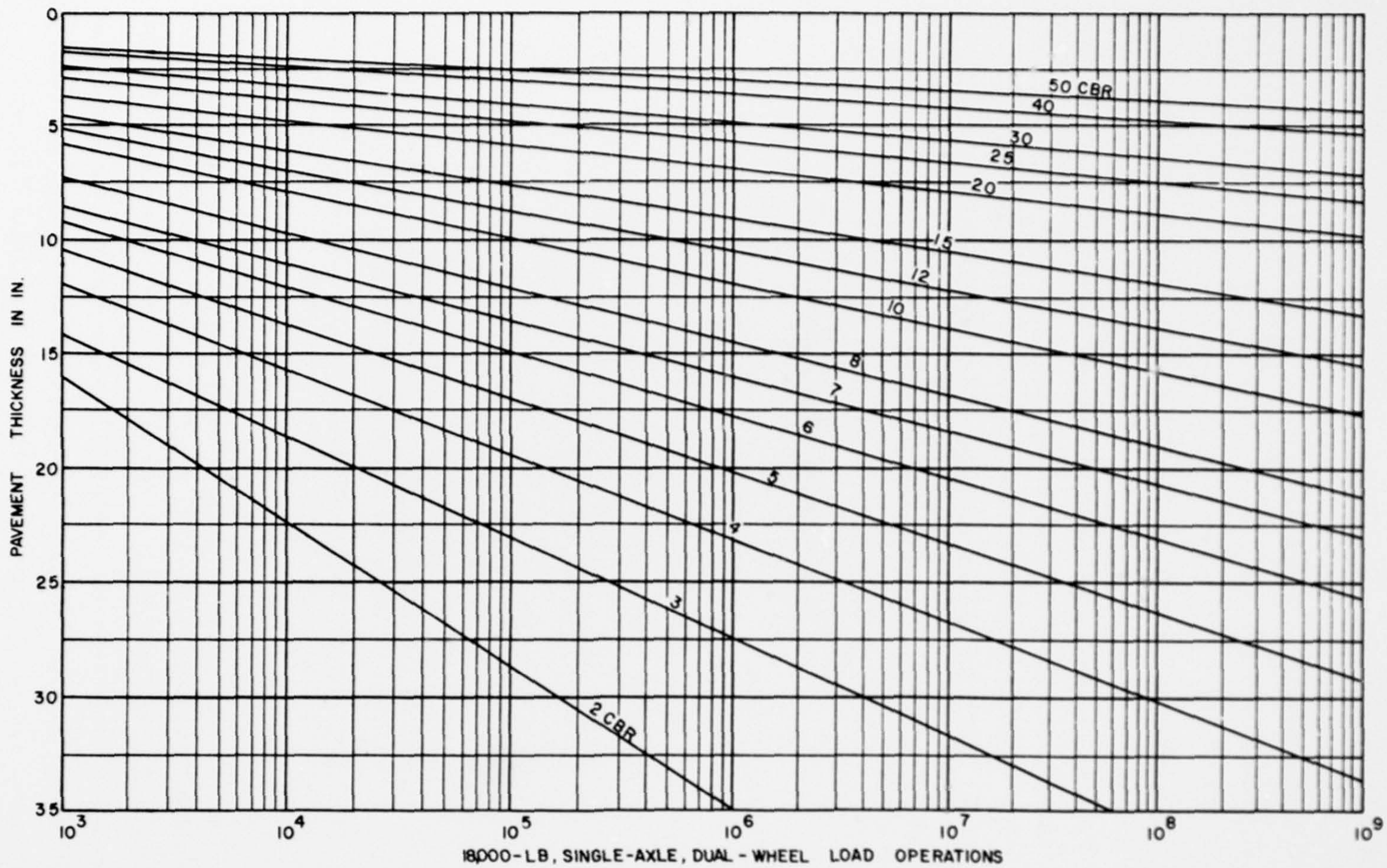


Figure 1. Flexible pavement design curves for roads, thickness versus operations for 18,000-lb, single-axle, dual-wheel load (Reference 1)

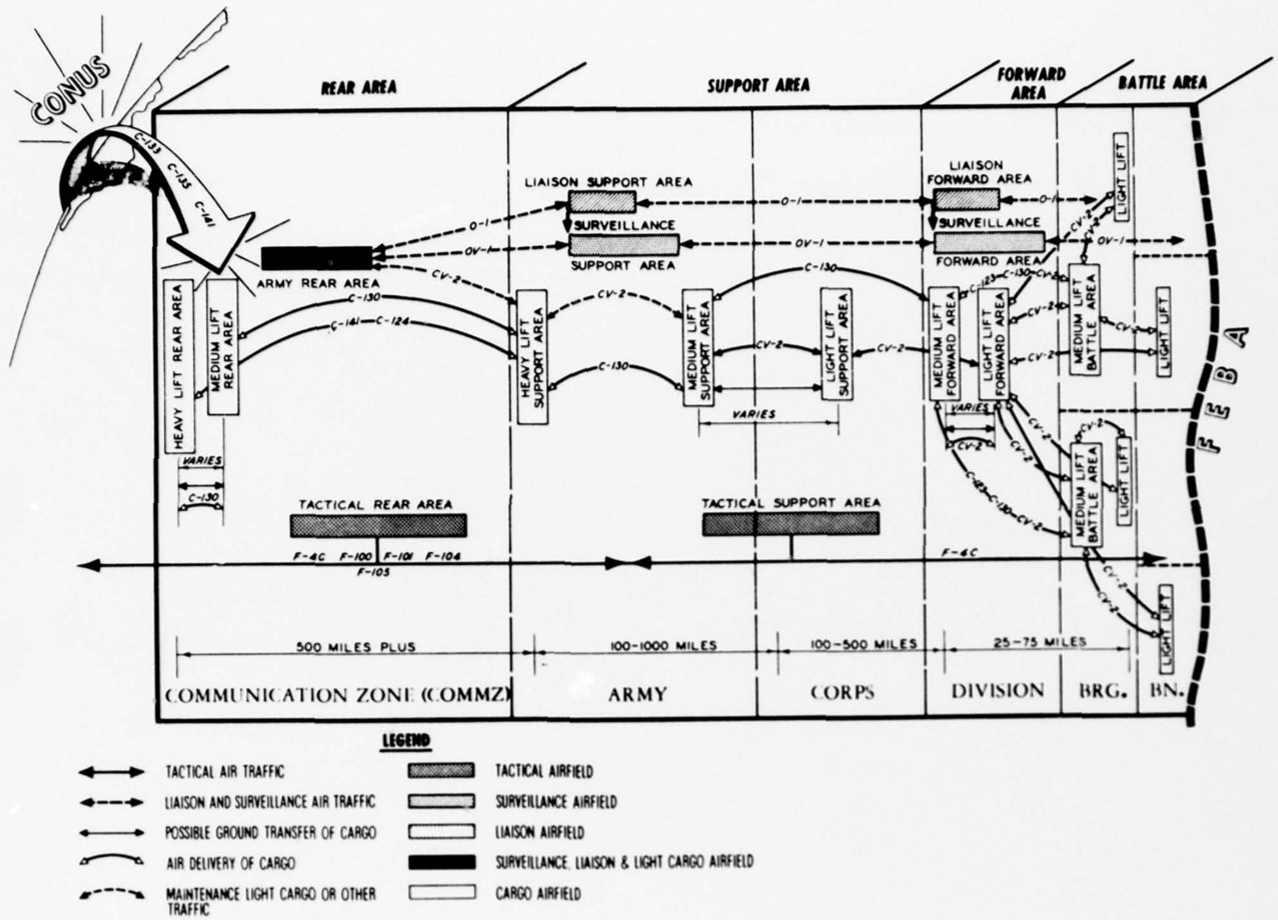


Figure 2. TO airfield concept, typical (Reference 1)

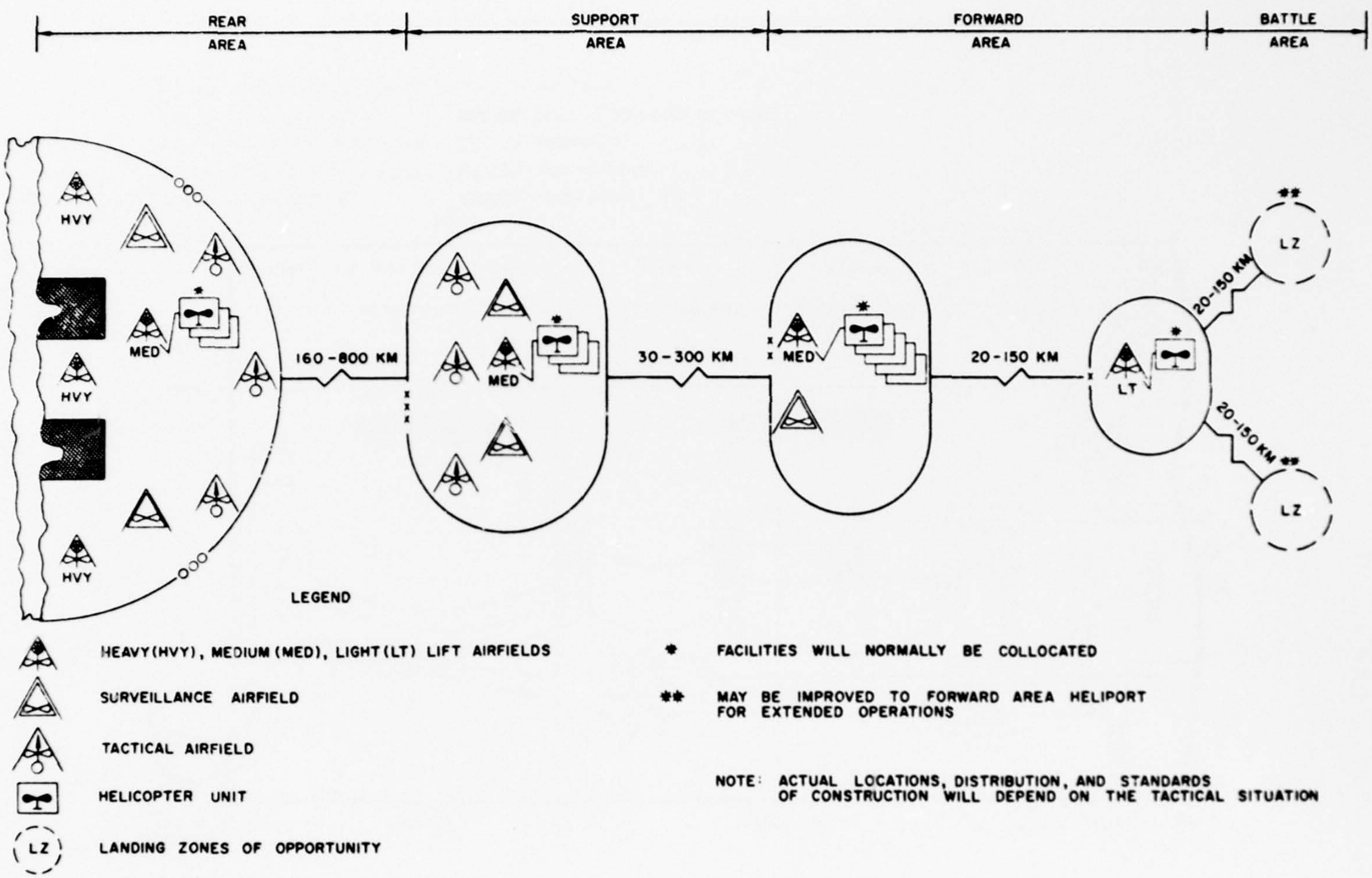


Figure 3. TO heliport concept, typical (Reference 1)

category to establish the limiting geometric and surface strength requirements. The categories and associated controlling aircraft are as follows:

a. Liaison (O-1).

b. Surveillance (OV-1).

c. Light-lift (C-7A).

d. Medium-lift (C-130).

e. Tactical (F-4C and F-105).

f. Heavy-lift (C-124, C-133, C-135, C-141, and C-5A).

10. Rotary-wing aircraft. Four helicopters designated as controlling helicopters (Reference 1, Chapter 11) to establish the limiting geometric and surface strength requirements for heliports are listed below:

a. Observation (light) helicopter (OH-6H).

b. Utility helicopter (UH-1D).

c. Cargo (medium transport) helicopter (CH-47).

d. Cargo (heavy-lift) helicopter (CH-54).

Airfield-heliport types

11. The airfield-heliport classification system[1] includes all known air missions for fixed-wing aircraft in the TO and selected helicopters with the appropriate military area. The airfield types are derived by combining the controlling aircraft classification with the appropriate military area.

Geometric requirements

12. Geometric requirements and typical layouts for various type TO airfields are presented in Reference 1 (Chapter 12). These requirements are based upon the characteristics of the controlling aircraft. Heliport criteria and layout are also given in Reference 1 (Chapter 14).

Surface requirements

13. Surface requirements and structural design criteria for the various type TO airfields are discussed in Reference 1 (Chapter 13). The smoothness requirements depend upon the type of aircraft and frequency of operations as well as the type of surfacing, if any. Criteria are given for the following four categories of airfield:

a. Unsurfaced airfields requiring a minimum preparation.

b. Membrane-surfaced airfields requiring fine grading.

c. Mat-surfaced airfields requiring fine grading.

d. Flexible pavements that are designed for high-performance jet aircraft and require smooth surfaces with not more than 1/8-in. deviation from a 12-ft straightedge.

Rigid pavements are not normally constructed in the TO. However, if existing rigid pavements are available, the surface smoothness requirements would be the same as for flexible pavements.

Structural requirements

14. Factors affecting the structural requirements for runways, taxiways, aprons, etc., for airfields and heliports are aircraft loading characteristics and design service life. The load-carrying capacity is dependent upon the strength of the subgrade and the thickness and quality of subbase, base, and pavement above the subgrade. Design and evaluation curves for unsurfaced, mat-surfaced, and flexible pavement facilities for various classifications of existing aircraft and helicopters are presented in Reference 1 (Appendix D). Figure 4 shows a typical curve representing subgrade strength requirements for a C-130 aircraft operating on unsurfaced or membrane-surfaced and surfaced with light- or heavy-duty landing mats. The strength is obtained from airfield penetrometer readings and expressed as the airfield index (Reference 1, Chapter 13). From the criteria shown in Figure 4, the soil strength (airfield index) required to support the C-130 aircraft is indicated for 10 to 5000 traffic cycles. As can be noted, the strength requirements increase as the number of traffic cycles increase. Also, higher strength is required for unsurfaced or membrane-surfaced soil than for the mat-surfaced soil.

15. A flexible pavement structure normally will consist of the subgrade, a subbase, a base course, and a bituminous concrete surface layer. Figures D-29 through D-43 (Reference 1, Appendix D) show the flexible pavement evaluation curves for all current military aircraft. These curves were developed for types A, B, and C traffic areas and for three categories of traffic, emergency, minimum, and full. These terms

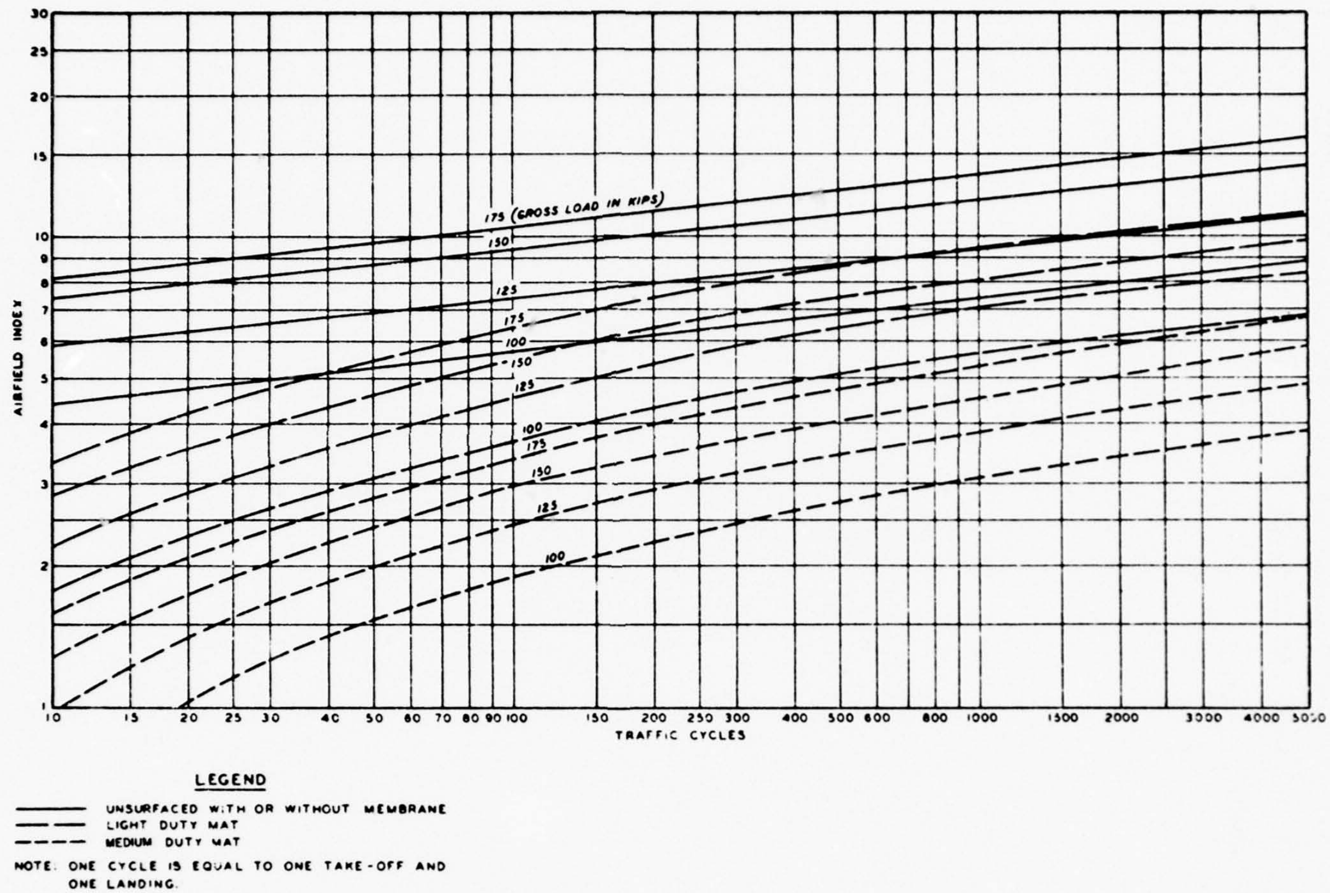
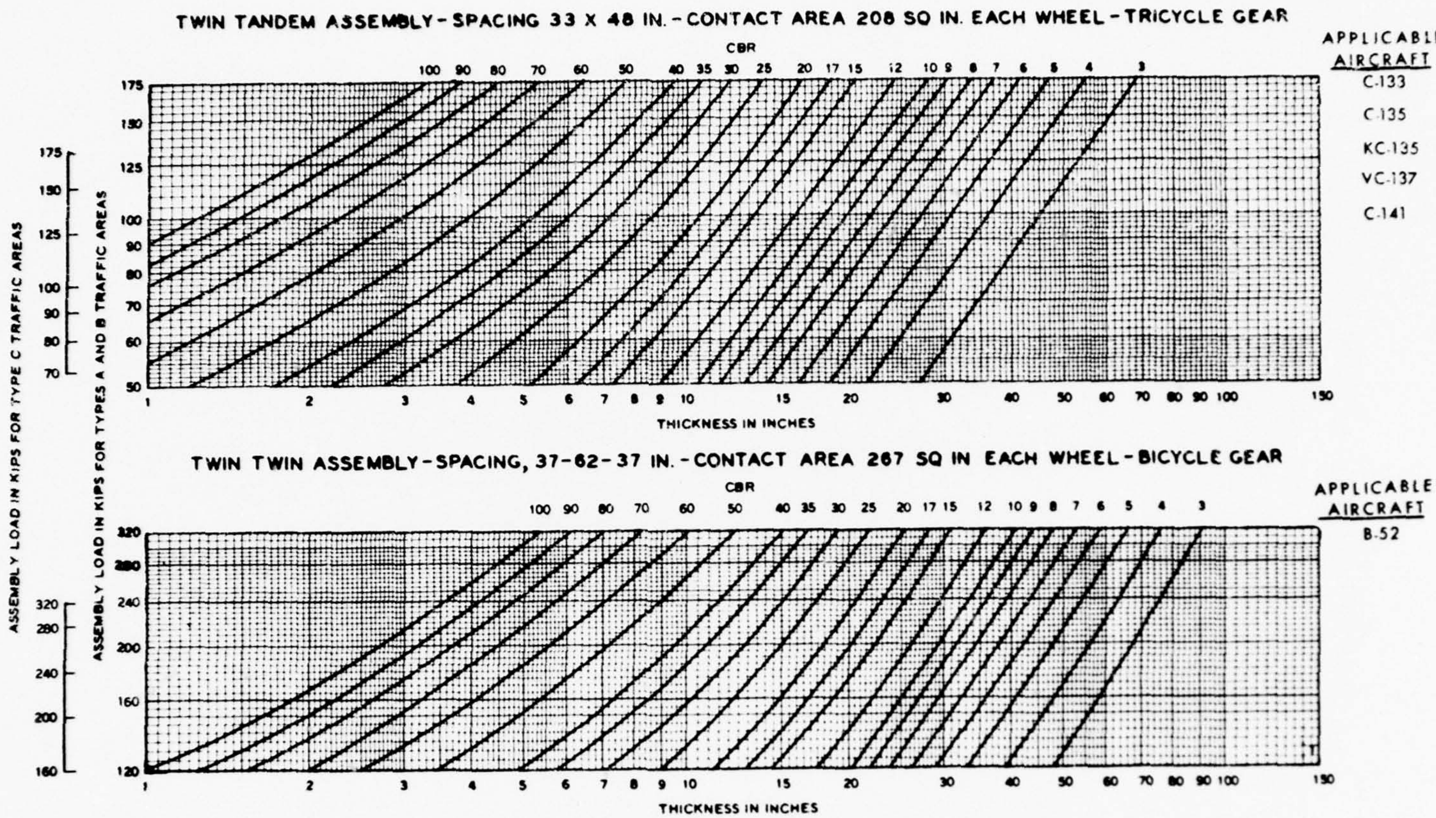


Figure 4. Subgrade strength requirements, C-130 aircraft, medium-lift rear area airfield (Reference 1)

are defined in Reference 1 (Chapter 13). Figure 5 shows typical flexible pavement evaluation curves for tricycle-type landing gear, twin-tandem and twin-twin assemblies, and full operational category.

16. TM 5-826-3[3] and TM 5-827-3[4] present evaluation curves for rigid pavements.



TYPE A TRAFFIC AREA - USE IN-PLACE THICKNESSES WITH THESE CURVES FOR MINIMUM OPERATION

TYPES B AND C TRAFFIC AREAS - USE IN-PLACE THICKNESSES WITH THESE CURVES FOR FULL OPERATION

Figure 5. Flexible pavement evaluation curves, tricycle-type landing gear, twin-tandem and twin-twin assemblies, full operational category (Reference 1)

PART III: EXPEDIENT METHODS OF EVALUATING EXISTING PAVEMENTS

Pavement Condition Survey

17. Condition surveys of existing roads, airfields, and heliports are necessary to determine the adequacy of an existing facility to meet mission requirements. The geometry of the facility, surface conditions, and structural or load-carrying capability must be evaluated in relation to the operational requirements for a specific mission. This evaluation can be accomplished by the following means.

Geometric survey

18. The geometry of various facilities may be obtained from intelligence data or from maps and drawings, if available. In some cases, ground reconnaissance may be necessary to adequately verify the existing geometry.

Surface conditions

19. The surface requirements vary considerably with the type of surface and mission requirement. As previously stated, the surface of a road, airfield, or heliport facility may be unsurfaced, membrane-surfaced, mat-surfaced, or consist of a flexible pavement or a rigid pavement. The surface condition for each type facility can be evaluated by visual observations and simple measurements. Observations and measurements needed for evaluating the suitability of each type surfacing is summarized as follows:

20. Unsurfaced. Determine and log the following information:

a. Soil type (Unified Soil Classification System (USCS) classification).

b. Vegetation (type, density, height, etc.).

c. Roughness (potholes, depressions, ruts, obstructions, etc.--location, size, and depth).

d. Drainage (good, fair, or poor).

e. Prior usage (type aircraft or vehicle).

21. Membrane-surfaced. Determine and log the following information:

a. Soil type (USCS classification).

b. Roughness (depressions, ruts, etc.--size and depth).

c. Conditions of membrane (holes, tears, open joints, etc.).

d. Drainage (good, fair, or poor).

e. Prior usage (type aircraft or vehicle).

22. Mat-surfaced. Determine and log the following information:

a. Soil type (USCS classification).

b. Roughness (depressions, ruts, etc.--location, size, and depth).

c. Type of mat (light, medium, or heavy-duty).

d. Condition of mat (mat breakage, deformed panels, and loss of subgrade support due to pumping action, etc.).

e. Skid resistance (condition of antiskid surface).

f. Drainage (good, fair, or poor).

g. Prior usage (type aircraft or vehicle).

23. Bituminous surfacing. Determine and log the following information:

a. Type of bituminous surface (bituminous surface treatment, asphalt concrete, tar concrete, rubberized-tar concrete, etc.).

b. Roughness (depressions, ruts, potholes, craters, etc.--location, size, depth, and maximum deviation from 12-ft straightedge).

c. Soundness (good condition--no excessive cracking, breaking up, or raveling; poor condition--badly cracked, raveling with loose aggregate on surface).

d. Skid resistance (good or poor).

e. Drainage (good, fair, or poor).

f. Prior usage (type aircraft or vehicle).

24. Portland cement concrete. Determine and log the following information:

a. Condition of joints and sealants (joint openings, spalling, faulting, etc.).

b. Roughness (craters, broken slabs, faults, and spalls--size, depth, and maximum deviation from 12-ft straightedge).

c. Soundness (good condition--relatively smooth with no excessive cracks, spalling, or loose material on surface;

poor condition--badly cracked, open joints and/or pumping mud through joints and openings).

d. Skid resistance (good or poor).

e. Drainage (good, fair, or poor).

f. Prior usage (type aircraft or vehicle).

Structural evaluation

25. The load-carrying capability of a soil or pavement structure is dependent upon the subgrade strength and the thickness and quality of the structural layers above the subgrade. Information needed for evaluating the load-carrying capacity of existing TO pavement facilities varies with the type of structure as is discussed in the following paragraphs.

Types of Pavement Structures

Unsurfaced,
membrane-, or mat-surfaced

26. Soil strength measurements for evaluating the load-carrying capability of unsurfaced soils or soils surfaced with membranes or landing mats may be obtained with an airfield penetrometer. The strength values are expressed in terms of airfield index. A complete description of the airfield penetrometer and its use in determining the airfield index is given in Reference 1 (Chapter 2). After the airfield index has been established, the load-carrying capability of the soil can be determined for each kind of forward, support, or rear area airfield through use of the subgrade strength requirement curves included in Reference 1 (Appendix D). These curves are based on correlations of aircraft performance and airfield indexes. As noted, the strength requirements for unsurfaced and membrane-surfaced soils are the same. The primary purpose of the membrane is for waterproofing and dustproofing, which result in an all-weather surface; whereas, for the unsurfaced condition, the soil strength may change rapidly with changing weather conditions, and in many cases usage will be limited to dry-weather operations. The strength requirements for the mat-surfaced soils for a given loading are less than for the unsurfaced or membrane-surfaced

soils and vary depending upon the type of mat (light- or medium-duty). Therefore, in evaluating the load-carrying capacity of a mat-surfaced soil, it is necessary to identify the type mat to use with the evaluation curves.

27. An expedient method of evaluating the adequacy of unsurfaced forward area airfields to support specific aircraft traffic has been developed by relating one-pass rut depth of ground vehicles to the requirements for operation of military aircraft. A direct evaluation can be made by applying one pass of a specific vehicle to an area, measuring the resulting rut depth made by the unpowered front wheels of the vehicle, then entering Table 2 with the measured rut depth and noting the allowable operation of a specific aircraft. The vehicle used for this evaluation should be operated with tire size as recommended by the Ordnance Command and at weights and tire pressures listed in Table 2. In order to measure the rut depth made by the unpowered front wheels, the vehicle should be stopped without braking, and measurement made between the front and rear wheels.

28. This method of evaluation was developed for cohesive soils only. However, for any corresponding rut depth in a cohesionless soil (sand), the load-carrying capacity would be better than indicated by Table 2.

29. The soil strength evaluation method is meant to give a rapid indication of the ability of a given aircraft to operate on an unsurfaced soil area and not as a substitute for existing methods. Existing standard methods of strength determinations should be employed when equipment and trained personnel are available.

Bituminous pavement

30. Detail procedures for evaluating the load-carrying capacity of flexible pavements are outlined in Reference 1 (Section III, Chapter 13). For this evaluation, the information needed involves strength in terms of CBR of the subgrade, CBR and thickness of subbase and base course layers, and total thickness of all structural layers above the subgrade, as well as the quality of the bituminous surface course. The exploration and testing required are time-consuming and, in many cases,

necessitate closing the facility to traffic while excavating test pits and conducting the essential sampling and testing operations. Therefore, detailed evaluations are limited, and expedient means of evaluation with good engineering judgment have to be used.

31. For those existing pavements that meet the minimum geometric and surface requirements that it is known have recently sustained loading equal to or greater than will be required for a given TO mission, no subsurface investigation will be required. However, if no data on the old pavement and no traffic history of previous usage are available, then the best evaluation possible, depending upon the combat situation, should be made.

32. A small aperture testing device has recently been developed for expedient evaluation of pavement structures. The equipment consisted of a small trailer-mounted drill rig (Figure 6) capable of cutting 6-in.-diam holes. The pavement layer is cored using a thin-wall diamond core barrel with water pumped into the core barrel to flush out the cuttings (Figure 7). A core-catcher tool (Figure 8) is used to remove the pavement core. The excess drill water left in the hole is removed immediately using a suction device. Further advancement of the test hole is made with a modified earth auger shown in Figure 9. The auger is 5-1/2 in. in diameter and has a flat end with a squared-off cutting edge. CBR tests are conducted in the core hole at the top of the base and subbase layers and to the desired depth into the subgrade. For the CBR test, a conventional CBR loading jack can be adapted to be quickly attached to the drill rig frame (Figure 10). It was found that good CBR test results could be obtained in the core holes and, by careful observations, the thickness of structural layers could be determined. Likewise, the material removed during the augering operation can be used for moisture determination and classification purposes. Laboratory tests can also be performed on the pavement cores to evaluate quality and strength.

Rigid pavement

33. Factors used in evaluating the load-carrying capacity of rigid portland cement concrete pavements are slab thickness, flexural

Figure 6. Trailer-mounted drill rig

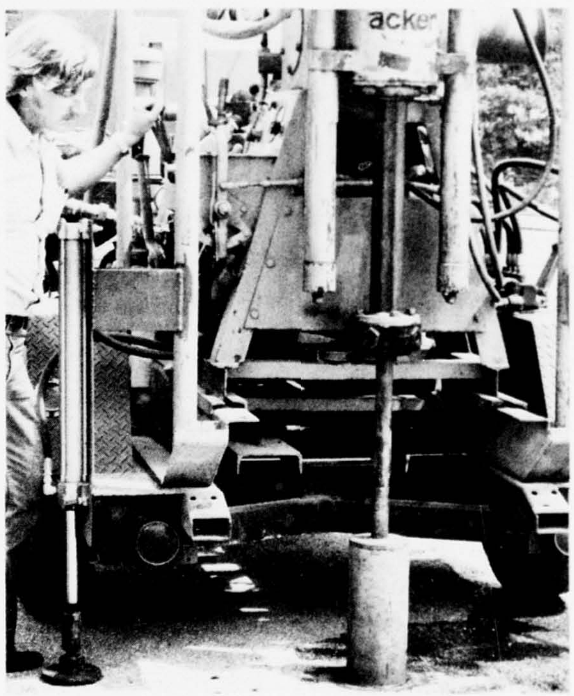


Figure 7. Coring the pavement layer

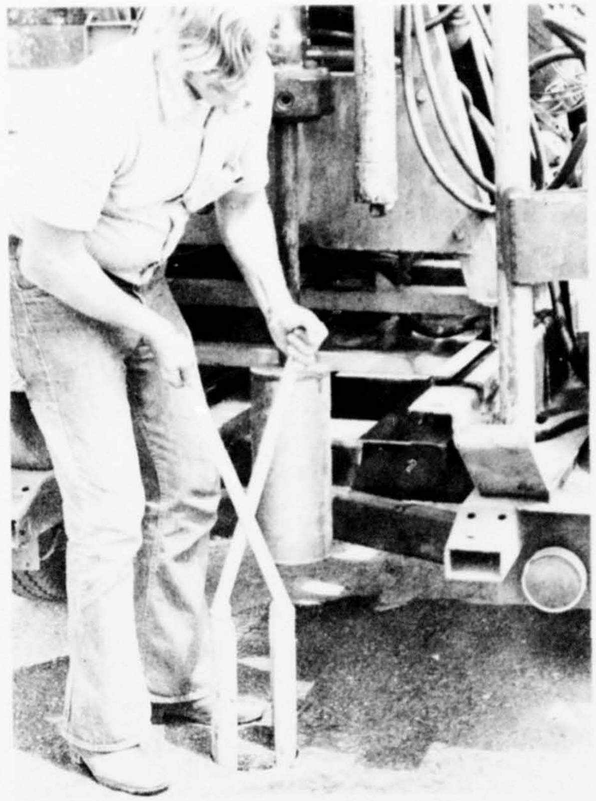


Figure 8. Removing a pavement core

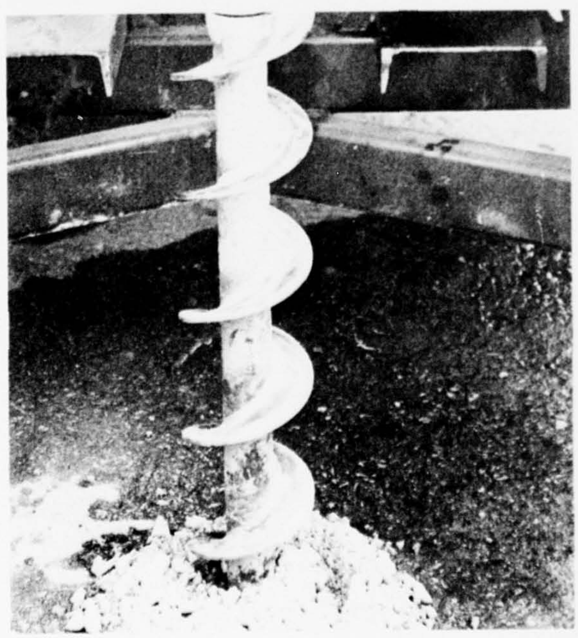


Figure 9. Modified earth auger

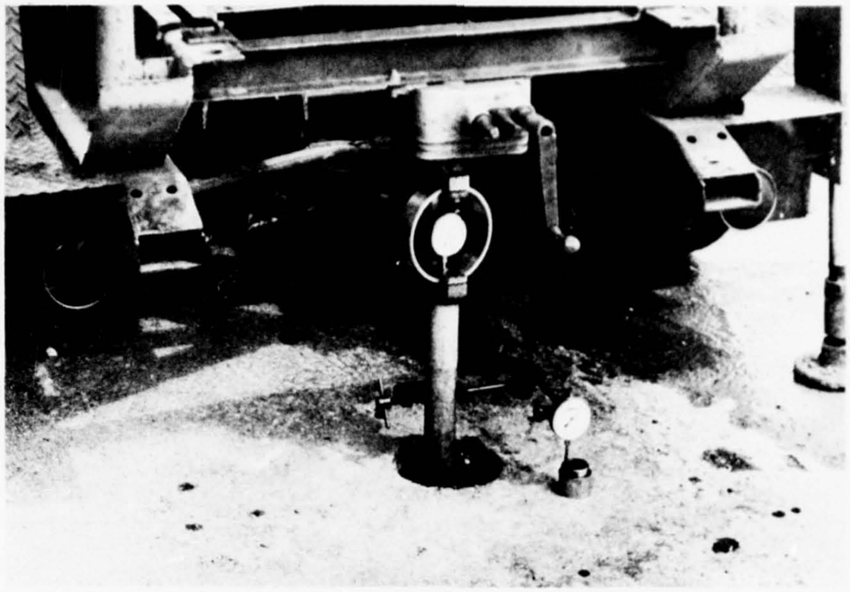


Figure 10. CBR test setup

strength of concrete, and modulus of subgrade or base reaction k . The modulus of subgrade reaction is normally obtained from plate bearing tests using a 30-in.-diam plate. The plate bearing test is not practical for evaluating pavements in the TO as it requires the removal of a rather large section of pavement for access to the subgrade. A fairly good approximation of the k value can be obtained from a CBR test and the correlation of subgrade reaction with CBR. Figure 11 shows a relationship of CBR and modulus of subgrade reaction k .[5] By using this relationship, the small aperture testing device previously described can be used for coring the pavement, and CBR values of the subgrade can be determined through the core hole. The 6-in.-diam core sample can be tested for tensile splitting strength using ASTM Test Method C 496-64T.[6] The flexural strength can be determined from the tensile splitting test results by using the relationship shown in Figure 12. The thickness of the concrete should be measured to the nearest 1/4 in. These values can then be used with the evaluation curves for rigid pavement[3,4] to determine the existing load-carrying capacity of the pavement.

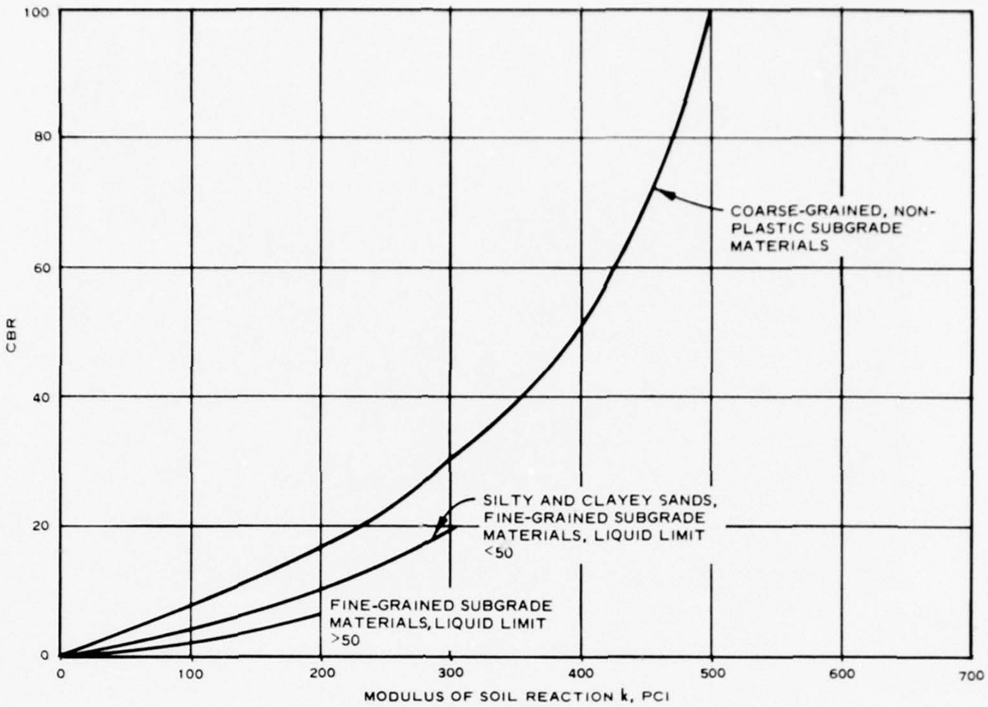


Figure 11. Relationship of CBR and modulus of subgrade reaction k

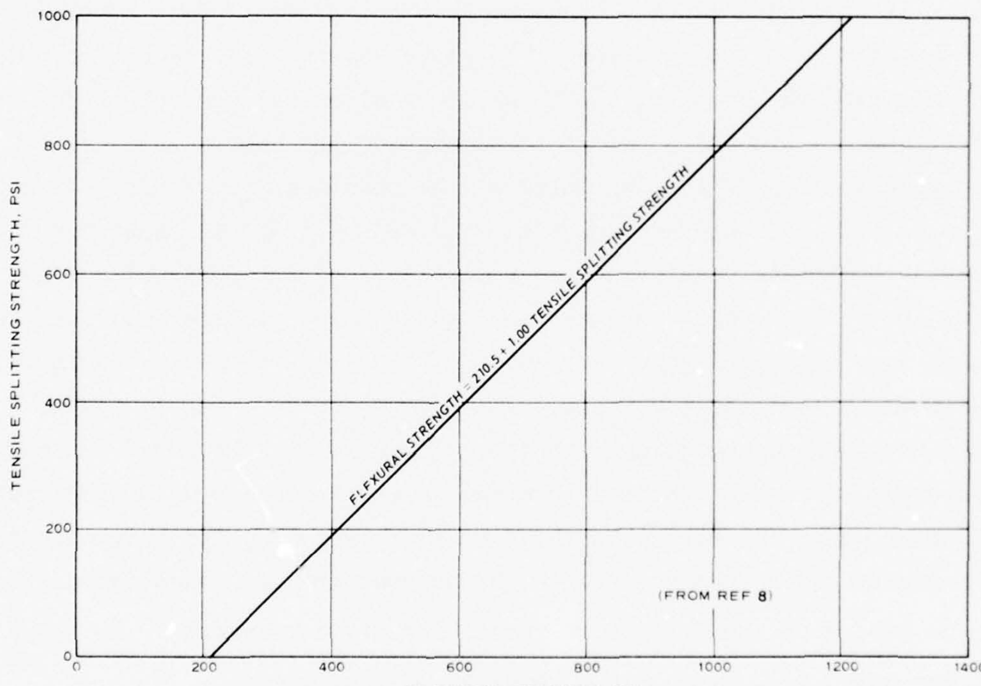


Figure 12. Relationship of tensile-splitting strength and flexural strength

PART IV: METHODS OF UPGRADING THEATER OF OPERATIONS (TO) PAVEMENTS

General

34. The method of upgrading existing TO roads, airfields, or heliports will depend upon the type of deficiency of the facility to meet mission requirements as determined in the condition survey. The deficiency may be involved in geometric features, surface condition, structural or load-carrying capacity, or a combination of these three. Alternate procedures of upgrading to eliminate different types of deficiences are presented below.

Geometric Features

35. Geometric features of a road, airfield runway, or taxiway apply to width, length, alignment, grades, etc. Where the existing features of a facility do not meet the minimum requirement for a given planned mission, such changes as widening, extensions, improvement in grades, and new alignments will be necessary. The magnitude of the construction effort will depend on several factors such as terrain, soil type, and vegetation. In many cases, a two-lane road can be widened to accommodate four or more traffic lanes, or a runway can be widened and lengthened as necessary to accommodate larger aircraft with much less construction effort and materials than would be required to construct a complete new facility. Therefore, these geometric improvements should always be considered. Construction practices would be the same as for new construction for a comparable facility.

Unsurfaced Roads, Airfields, and Heliport Facilities

Surface deficiencies

36. The basic requirements of an unsurfaced road, airfield runway, or heliport facility are (a) that it meets the geometric requirements,

(b) that it has sufficient bearing capacity to support the traffic loads, and (c) that the surface conditions, roughness, obstructions, rutting, etc., are such that a given vehicle or aircraft can operate with a reasonable degree of safety. It may consist of a prepared surface or be an unprepared natural terrain. In any case, surface irregularities such as ditches, potholes, and stumps, which exceed the limits specified for a given type facility, must be corrected. Potholes, ditches, etc., can be filled with the native soil. Stumps, roots, brush, or any other obstruction should be cut even with the ground.

37. The big problem areas in operations on unsurfaced facilities are dust during dry weather and mud in wet weather. This is particularly true for fine-grained cohesive soils. The strength of fine-grained cohesive soils is very sensitive to soil water content and the degree of compaction. In fact, the strength may be very high in dry weather and very low when wet, making the facility completely unserviceable. On the other hand, sands and free-draining granular materials will retain their strength in wet weather and, in many cases, will support loads better if wet than when dry.

38. Upgrading of unsurfaced roads, airport, and heliport facilities can be accomplished by grading and compaction of surface soil layers and by providing a good crowned cross section and good surface drainage. The application of dust palliatives and waterproofing materials is also quite beneficial. However, prior to using these materials, Reference 7 (Chapter 12) should be consulted to obtain guidance in their selection and application.

Load-carrying capability

39. When the load-carrying capacity, airfield index, or CBR of an unsurfaced soil facility is less than that required to support a given mission, upgrading can be accomplished by a number of different methods depending upon the availability of equipment, materials, construction personnel, and time available. Alternate procedures which should be considered are as follows:

a. Base course. Construct a base course of adequate thickness and quality to distribute load to the subgrade.

Criteria for determining thickness and quality requirements are summarized in Reference 1 (Chapter 13).

b. Soil stabilization. The strength or load-carrying capacity of soil and aggregate materials can be upgraded by stabilization. Expedient procedures have been developed to aid the military engineer in evaluating or identifying the soil type and in selecting the type and quantity of stabilizing agent needed for stabilization based upon soil classification. An Instruction Report No. S-74-3 entitled "Stabilization of Soil and Aggregate Materials for Forward Area Operations" was prepared for troop use and is included herein as Appendix A. Construction procedures and equipment needed for in-place subgrade stabilization and for stabilized base courses are discussed in the appendix. Soil stabilization is also covered in detail in Reference 1 (Chapter 2).

c. Membrane encased soil layers (MESL). A MESL base course is especially applicable in areas where fine-grained soils are available and in low-lying areas where groundwater intrusion into the foundation materials is prevalent during wet seasons. The MESL concept involves complete encasement of a highly compacted fine-grained soil layer in a waterproof membrane. This prevents the soil from becoming wet due to surface or subsurface moisture. A MESL base can be used as a wearing course or as a base course for a flexible or rigid pavement structure. Limited instruction on MESL construction is given in Appendix A. More detailed instructions are presented in References 8 and 9.

d. Landing mats. Surfacing with prefabricated metal landing mats is an expedient means of upgrading an existing unsurfaced soil for roads or airfield and heliport facilities. Complete procedures for the use of landing mats are described in Reference 1 (Chapter 13).

e. Bituminous surfacing. Bituminous surfacing is a conventional method of upgrading existing unsurfaced roads, airfields, and heliport facilities; and standard procedures for the design and construction of various type bituminous surfaces are discussed in References 1 and 2. Studies currently under way at the U. S. Army Engineer Waterways Experiment Station (WES) indicate that adequate asphalt concrete pavements for most TO road requirements can be made from marginal pit-run granular materials, which do not meet the quality and gradation requirements as currently specified. The testing and evaluation is incomplete at this time. However, most granular materials, such as sand, gravelly sand, or gravelly clayey sands, with up to 15 to 20 percent passing a 200 mesh screen can be used with about 6 percent asphalt cement

in hot-mix asphalt paving mixtures, which will provide an adequate road surface for TO requirements.

Landing-Mat-Surfaced Airfield and Heliport Facilities

Surface deficiencies

40. Surface defects in landing-mat-surfaced facilities that may require upgrading consist of mat breakage or excessive roughness. Mat breakage is normally a result of fatigue due to a large number of load repetitions and is related to the subgrade strength and the degree of mat deflection under load. Cavities may form under the mat due to erosion of soil from under the mat or to pumping action at mat joints. Where water gets through the mat to the soil, water and soil may be pumped up onto the surface of the mat by the using aircraft or vehicle. This type of action will ultimately lead to mat failures and to excessive roughness and loss of subgrade strength. Surface deficiencies may be upgraded by the following methods:

a. Grouting under mat. Where excessive roughness has developed in a mat-surfaced facility due to cavities or voids under the mat and where the mat is still structurally sound, the voids can be filled by grouting with a soil cement grout as described in Reference 10. Grouting under mat should only be considered for filling voids and restoring the grade where the subgrade strength is adequate. If the subgrade strength has deteriorated to below the design strength for the mat-surfaced facility, the grouting would be of little or no value.

b. Mat overlay. Procedures have been developed for overlaying deteriorated rough landing mat surfaces with new landing mat.[11] This procedure will normally require the construction of a soil cushioning layer over the old mat to restore grade and provide for a smooth seating surface for the new mat. This overlay procedure will provide an increased load-carrying capacity of the structure as well as correcting surface deficiencies.

Load-carrying capability

41. In any case where the subgrade strength is less than the minimum design strength indicated for a given mat type and controlling aircraft loading, rapid deterioration of the mat facility can be expected.

If a cohesive subgrade soil beneath a mat becomes wet due to poor drainage or inadequate waterproofing techniques used during construction, the subgrade will lose strength, resulting in excessive deformations and rapid mat deterioration. Where this occurs, about the only way to restore the strength in the subgrade is to remove the mat, dry out the wet soil to about optimum water content, grade and compact as necessary to obtain the desired grade and strength, and then replace the mat. A waterproof membrane should always be placed over the subgrade prior to placing the mat to prevent surface water from getting to the subgrade soil. In replacing the mat, any badly deformed or structurally damaged planks should be replaced with new mat.

42. Chemical stabilization of the subgrade soil with lime, portland cement, or asphalt, depending upon the soil type, will improve the strength and load-carrying capacity and make the soil less sensitive to erosion and loss of strength due to moisture.

Bituminous and Portland Cement Concrete Surfaces

Bituminous overlays

43. Bituminous overlays are effective in upgrading old pavements (a) to improve riding quality, appearance, and waterproofing, and (b) to increase skid resistance and load-carrying capacity of the pavement. The most common type of bituminous overlay is asphalt concrete, although other types, such as tar or rubberized-tar concrete, sheet asphalt, and cold mix, may be used.

44. The type, quality, and thickness of overlay needed is dependent upon the purpose for which the overlay is placed and the planned mission for the pavement facility. For example, an airfield runway, which is structurally sound with adequate load-carrying capability, is very rough due to differential settlements, and the existing bituminous surfacing is badly cracked. The thickness of overlay required for this condition would be the minimum required to fill depression and restore a smooth waterproof riding surface that meets the design smoothness criteria for the specific runway. On the other hand, if the overlay is

being placed to increase the load-carrying capacity of the runway, the thickness of overlay required over existing bituminous pavements can be determined from the design and evaluation curves shown in Reference 1 (Appendix D). This determination is made by comparing the existing CBR of the structural layers below the pavement surface (base, subbase, and subgrade) with the design curve for the controlling aircraft and by reading the design thickness required above each layer of the pavement structure. The following is an example of an overlay design to increase load-carrying capacity:

a. The requirement states that it is desirable to use an existing flexible pavement runway as part of a rear area full operational airfield capable of handling C-141 aircraft with design load of 150,000 lb.

b. From the condition survey, it is found that the existing structure consists of the following elements:

Structural Layer	CBR	Layer Thickness in.	Thickness Above Each Element in.
Asphalt concrete	--	3	0
Granular base course	50	6	3
Granular subbase	25	26	9
Cohesive subgrade	5	--	35

c. From the design and evaluation curves for the C-141 aircraft with 150,000-lb gear load full operational category (upper part of Figure 5), the indicated thicknesses required above the various structural layers of the existing pavement are as follows:

Structural Layer	CBR	Required Thickness in.
Asphalt concrete	--	--
Granular base course	50	6.5
Granular subbase	25	12.0
Cohesive subgrade	5	42.0

d. By comparison of the actual thicknesses above the various structural layers with the required design thickness as indicated above, the overlay thickness needed to satisfy the mission requirements would be about 7 in.

45. Design procedures for bituminous or flexible overlays over rigid portland cement concrete pavements are discussed in References 12 and 13.

46. Mix design. Mix design procedures for bituminous mixtures for overlay purposes are the same as for new construction (see References 2 and 14 for details of procedures and criteria for selection of the optimum mixture). Asphalt cement is more commonly used as a binder in bituminous paving mixtures. However, in areas of airfield pavements where jet fuel spillage is a problem, tar or rubberized-tar concrete mixes have an advantage in that tar is more resistant to jet fuels and solvents than is asphalt cement. Dense-graded mixes of rubberized-tar concrete are highly resistant to jet fuel and are less susceptible to damage by high temperatures than tar concrete.

47. Preparation prior to overlay. The preparation of an existing pavement for a bituminous overlay consists of cleaning the surface of all foreign matter; filling any potholes, craters, etc.; repairing any localized failed areas of the pavement base or subgrade; and applying tack coat. In the case of old rigid pavements to be overlaid by all-bituminous overlay, any voids detected beneath the base pavement should be filled by grouting or undersealing prior to the overlay. Any spalled concrete, extruded joint seal, and other materials that would prevent the overlay from bonding to the base pavement should be removed. Where joints or cracks in the existing pavement are sufficiently wide to hold a sand-asphalt mixture, the joints or cracks should be cleaned out and filled with a sand-asphalt mixture containing about 3 percent residual asphalt.

48. Mixing and placing overlay. The same procedures are used in the manufacture and placement of bituminous overlay pavements as for new construction.[2]

Landing mat overlay

49. Landing mat overlays provide an expedient effective method of upgrading existing deteriorated airfield pavements. For pavements that are relatively smooth but have inadequate load-carrying capacity for the required military mission, the placement of the landing mat overlay

directly over the existing pavement will significantly increase the load-carrying capacity of the pavement. Where existing pavements have deteriorated to such an extent that the surface roughness of the runway or taxiway precludes operation of the mission aircraft, it may be necessary to construct a cushion layer of soil over the deteriorated surface in order to provide a smooth seating surface for the mat (see Reference 11 for detailed procedures).

50. Landing mat was used as an overlay over a weak deteriorated flexible pavement runway during field exercises at Oak Grove, North Carolina, for 4 consecutive years (1973-1976). The performance of the mat overlay under C-130 aircraft operations was observed and documented.

51. From the results of the exercises at Oak Grove and related studies conducted at WES, the following conclusions and recommendations have been drawn:

- a. The use of landing mats over existing deteriorating pavements will greatly increase the load-carrying capacity of the structure and prevent foreign object damage to aircraft.
- b. If the deteriorated condition or roughness of the field dictates that a soil leveling course is needed, a lightweight waterproof membrane should be placed between the soil and mat to prevent pumping of the soil through the mat joints during wet weather.
- c. The ends and edges of the mat overlay should be securely anchored to minimize excess slippage and horizontal mat movement under aircraft traffic.

52. Complete instructions for the installation of XM18, XM19, and trussweb mats are outlined in References 15, 16, and 17, respectively.

Recycling deteriorated pavements

53. General. Due to the scarcity and high cost of high-quality paving aggregates and binders, such as asphalt cement, considerable interest has developed in recent years in recycling techniques for salvaging these materials in existing deteriorated pavement structures. Several different methods of recycling old deteriorated pavements have been evaluated. Whereas all these methods have merit, probably the method that would have the best application in the TO would be in-place recycling. This process is applicable only to bituminous pavements and is discussed below.

54. <u>In-place recycling.</u> The basic process is shown by the flow chart in Figure 13. The first step involves preparing the pavement by cutting the perimeter of the construction and lowering all structures (water and gas shutoffs, manholes, etc.) to below the depth of pulverization. The pavement is then ripped or scarified and broken into pieces with a maximum size of 4 to 5 in. The broken pavement is pulverized to the required specification and mixed with a predetermined amount of the existing aggregate base. If necessary, this mixture can be windrowed to the side so that the subbase can be reworked. The residual asphalt in the pulverized material will provide a good binder for a recycled stabilized base; however, additional stabilizing agents such as lime, cement, or asphalt, are normally required to assist in the stabilization process. The reclaimed mixture is then spread to the desired grade and compacted to form a new stabilized base course. A tack or prime coat of bitumen is applied as required, and, if desired, a new bituminous wearing surface is placed over the stabilized base. Finally, all structures are adjusted, and the area is cleaned and dressed.

55. Equipment used in the process is of standard road-building type. Motorgraders with scarifiers or bulldozers with ripper teeth and sheepfoot rollers are used for the initial breakup. Heavy-duty pulvemixers are used for pulverizing and mixing the material. Conventional distributors and mixers are used to spread and combine any additional stabilizing agent. Regrading of the subbase and the recycled stabilized base is accomplished with motorgraders, and compaction is obtained with static steel-wheel pneumatic-tired, or vibratory rollers. The new wearing surface, if required, is placed and compacted using conventional equipment and methods.

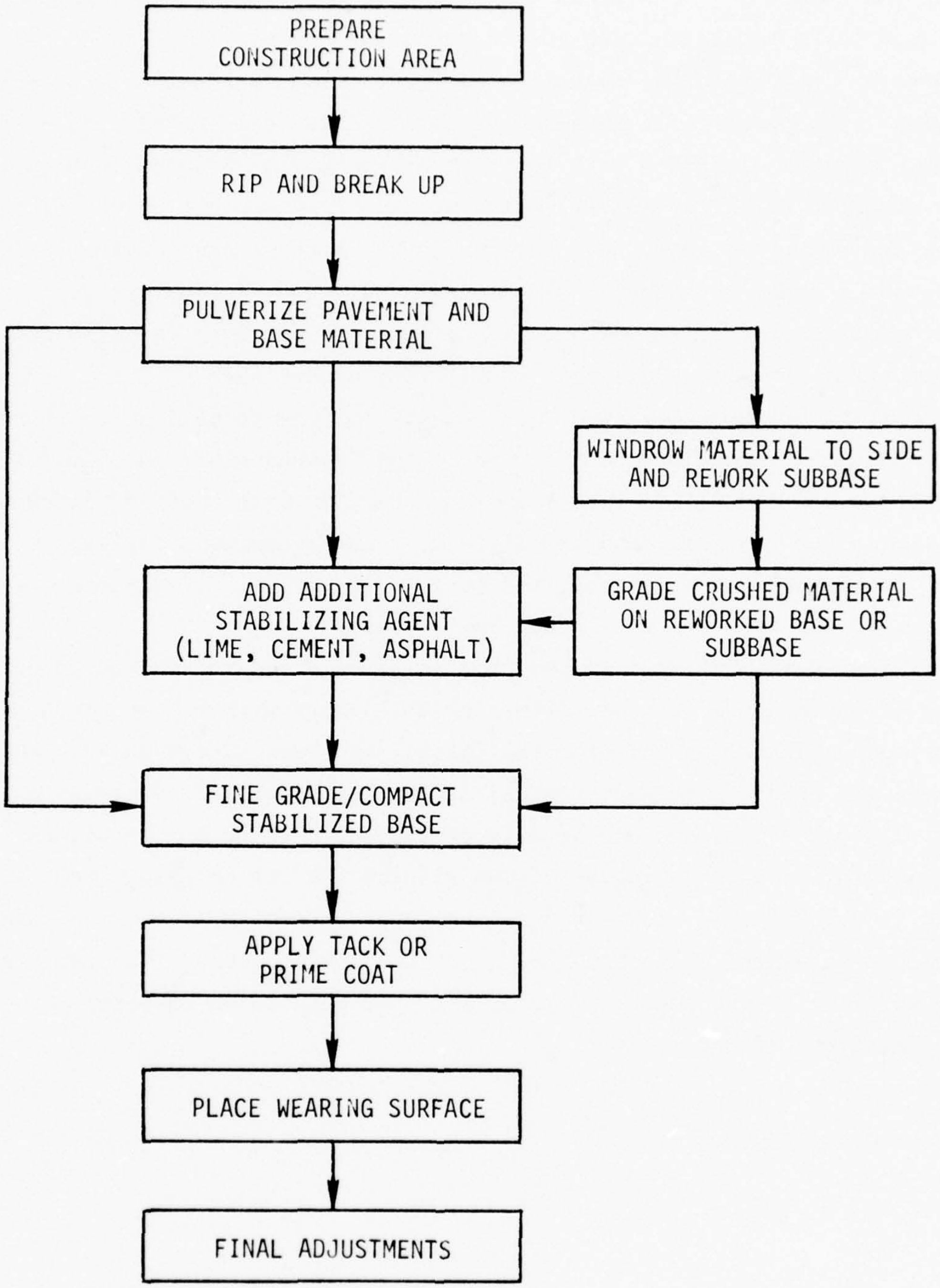


Figure 13. Process flow chart - pulverize in-place

PART V: CONCLUSION

56. The evaluation procedures and alternate procedures for upgrading deteriorated TO pavements presented herein have been validated in prototype pavement structures under actual or simulated vehicular or aircraft traffic. In selecting the method of upgrading for a specific situation, consideration must be given to the urgency, equipment, materials, and personnel available to accomplish the mission.

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Table 1

Summary of Military Road Specifications*

Characteristic	Specification
1. WIDTH:	
Traveled way (single lane)	Minimum--11-1/2 ft.
Traveled way (two lanes)	Minimum--23 ft.
Shoulders (each side)	Minimum--4 ft.
Clearing	Minimum--6 ft. on each side of roadway.
Widening on curves	See Table 10-5 (TM 5-330).
2. ALINEMENT:	
Grades:	
Absolute maximum	Maximum grade vehicle can travel on.
Normal maximum	10 percent.
Desirable maximum	Tangents and gentle curves, less than 6 percent; sharp curves, less than 4 percent.
Horizontal curve radius	Minimum--150 ft.
Vertical curve length:	
Invert (sag) curves	100-ft minimum for each 4 percent algebraic difference in grades.
Overt (crest) curves	125-ft minimum for each 4 percent algebraic difference in grades.
Slight distance:	See Table 10-2 (TM 5-330).
3. LOAD OPERATION CAPACITY:	
Road proper	Sustain design number of equivalent 18,000-lb axle-load operations/day.
Bridges	Accommodate using traffic.
4. SLOPES:	
Shoulders	3/4 inch per foot.
Crown (gravel and dirt)	1/2 to 3/4 inch per foot.
Crown (paved)	1/4 to 1/2 inch per foot
Superelevation (gravel and dirt)	1/2 to 1-1/4 inch per foot.
Superelevation (paved)	1/4 to 1-1/4 inch per foot.
Cut	Variable.
Fill	Variable.
5. Miscellaneous:	
Overhead clearance	Minimum--14 feet.
Traffic volume	2,000 vehicles per day.
Turnouts (single lane)	Minimum--every 1/4 mile.

* See Reference 1.

Table 2

Standard Military Ground Vehicles Related to Operation of Military Aircraft on Unsurfaced Fields

VEHICLE	VEHICLE WEIGHT LB	TIRE PRESSURE PSI	RUT DEPTH IN.	AIRCRAFT LOADING	AIRCRAFT OPERATIONS*	PREDICTED OPERATIONAL CAPABILITY FOR VARIOUS TYPES OF AIRCRAFT**											
						0-1	U-6	C-45	U-1A	U-8	C-7A	C-47	OV-1	CH-47	CH-54	C-123	C-130
1/4-TON, 4x4 M151 TRUCK	2,473 EMPTY	20	0	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			TRACE 0.1	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.25	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
	3,000 DRIVER AND 3 PASSENGERS	20	0	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			TRACE 0.1	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.25	EMPTY	1 10 100												
				FULL LOAD	1 10 100												

* One operation is one takeoff and one landing.

** Aircraft can operate at indicated loading.

Aircraft cannot operate at indicated loading.

Aircraft may be able to operate at indicated loading with calculated risk.

Table 2 (Continued)

VEHICLE	VEHICLE WEIGHT LB	TIRE PRESSURE PSI	RUT DEPTH IN.	AIRCRAFT LOADING	AIRCRAFT OPERATIONS	PREDICTED OPERATIONAL CAPABILITY FOR VARIOUS TYPES OF AIRCRAFT											
						0-1	U-6	C-45	U-1A	U-8	C-7A	C-47	OV-1	CH-47	CH-54	C-123	C-130
3/4-TON, 4x4 M37 TRUCK	5,950 EMPTY	50	0	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.1	EMPTY	1 10 100												
			0.1	FULL LOAD	1 10 100												
			0.25	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
	7,800 LOADED	50	0	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			TRACE 0.1	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.25	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.50	EMPTY	1 10 100												

(Sheet 2 of 5)

Table 2 (Continued)

VEHICLE	VEHICLE WEIGHT LB	TIRE PRESSURE PSI	RUT DEPTH IN.	AIRCRAFT LOADING	AIRCRAFT OPERATIONS	PREDICTED OPERATIONAL CAPABILITY FOR VARIOUS TYPES OF AIRCRAFT											
						0-1	U-6	C-45	U-1A	U-8	C-7A	C-47	OV-1	CH-47	CH-54	C-123	C-130
2-1/2-TON, 6x6 M34 TRUCK	13,900 EMPTY	70	0	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			TRACE 0.1	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.25	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.5	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			1.0	EMPTY	1 10 100												

(Sheet 3 of 5)

Table 2 (Continued)

VEHICLE	VEHICLE WEIGHT LB	TIRE PRESSURE PSI	RUT DEPTH IN.	AIRCRAFT LOADING	AIRCRAFT OPERATIONS	PREDICTED OPERATIONAL CAPABILITY FOR VARIOUS TYPES OF AIRCRAFT											
						0-1	U-6	C-45	U-1A	U-8	C-7A	C-47	OV-1	CH-47	CH-54	C-123	C-130
2-1/2-TON, 6 x 6 M34 TRUCK (Continued)	24,300 LOADED	70	0	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			TRACE 0.1	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.25	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.50	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			1.0	EMPTY	1 10 100												
				FULL LOAD	1 10 100												

(Sheet 4 of 5)

Table 2 (Concluded)

VEHICLE	VEHICLE WEIGHT LB	TIRE PRESSURE PSI	RUT DEPTH IN.	AIRCRAFT LOADING	AIRCRAFT OPERATIONS	PREDICTED OPERATIONAL CAPABILITY FOR VARIOUS TYPES OF AIRCRAFT											
						0-1	U-6	C-45	U-1A	U-8	C-7A	C-47	OV-1	CH-47	CH-54	C-123	C-130
5-TON, 6x6 M55 TRUCK	24,064 EMPTY	70	0	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			TRACE 0.1	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.25	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			0.50	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			1.0	EMPTY	1 10 100												
				FULL LOAD	1 10 100												
			2.0	EMPTY	1 10 100												
				FULL LOAD	1 10 100												

(Sheet 5 of 5)

APPENDIX A: STABILIZATION OF SOIL AND AGGREGATE MATERIALS FOR FORWARD AREA OPERATIONS (PUBLISHED IN SEPTEMBER 1974 AS INSTRUCTION REPORT S-74-3)

PREFACE

This instruction report was prepared as a part of the work authorized by the Office, Chief of Engineers, U. S. Army, under Military Engineering Design and Expedient Construction Criteria, Project No. 4A062103A859, Task 08, Work Unit 010 Q6, "Stabilized Layers for Pavements (Stabilization of Native Soil)."

Engineers of the Soils and Pavements Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), who were actively engaged in the planning, testing, and analyzing phases of the study that led to the preparation of this report were Messrs. Ronald L. Hutchinson, Alfred H. Joseph, Cecil D. Burns, and Robert W. Grau. This work was performed under the general supervision of Messrs. James P. Sale and Richard G. Ahlvin, Chief and Assistant Chief, respectively, of the Soils and Pavements Laboratory. This report was written by Mr. Grau.

Directors of WES during the preparation of this report were BG E. D. Peixotto, CE, and COL G. H. Hilt, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
square inches	6.4516	square centimeters
square yards	0.8361273	square meters
gallons (U. S. liquid)	3.785412	cubic decimeters
pounds	0.45359237	kilograms
kips	0.45359237	metric tons
tons	0.90718474	metric tons
pounds per cubic inch	27,679.90	kilograms per cubic meter
pounds per cubic foot	16.018489	kilograms per cubic meter
pounds per square inch	0.6894757	newtons per square centimeter
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

STABILIZATION OF SOIL AND AGGREGATE MATERIALS FOR FORWARD AREA OPERATIONS

PART I: INTRODUCTION

Purpose and Scope

1. The intent of this report is to provide information and guidance to military engineers in determining the most expedient methods and procedures for upgrading in-place soil in the construction of airfields, roads, heliports, and storage areas in forward areas of a theater of operations (TO). Specifically, this report presents procedures for determining which method or methods are applicable for improving the physical properties of an available material and suggested construction techniques for doing so.

General Considerations

2. The methods for improving the physical properties of soils are mechanical and chemical stabilization and waterproofing techniques. Mechanical stabilization refers to the compaction and/or the blending and compaction of soils to produce a more desirable construction material. Chemical stabilization is the process of upgrading the construction characteristics of a soil by the addition of additives. Bitumen, lime, and portland cement are the chemical additives used for upgrading soils in TO construction. Waterproofing of the surface by installing membranes and, for certain conditions, by encapsulating a compacted soil layer for a foundation is another method of stabilizing and upgrading the construction qualities of soils.

3. Selection of the mode of inprovement depends greatly on the type of material available; however, drainage characteristics of the terrain, equipment required, and the prevailing weather conditions during the proposed construction period are also important considerations.

The material in question should be classified either by the Unified Soil Classification System (USCS)* or, in case laboratory soil testing is impossible due to lack of time or facilities, by a field identification system. If the gradation of the soil can be controlled, mechanical stabilization will probably be the most economical and expedient method of altering the existing material. However, in many instances, a low-quality material may require either chemical stabilization or a membrane-enveloped soil layer (MESL) before it is acceptable as a construction material. MESL-type construction should be employed only when the prevailing weather conditions during the construction period will remain relatively dry.

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* Department of Defense, "Unified Soil Classification System for Roads, Airfields, Embankments, and Foundations," Military Standard No. MIL-STD-619B, Jun 1968, Washington, D. C.

PART II: PROCEDURE FOR SELECTING STABILIZATION METHOD

Soil Identification

4. The in-place soil that is to be upgraded should first be classified in order to determine the best approach to stabilization based on the materials and equipment available.

USCS

5. The USCS is used to identify soils according to their particle-size distribution and plasticity. Soils seldom exist in nature separately as sand, gravel, or any other single component but are usually found as mixtures with varying properties of particles of different sizes. Each component part contributes its characteristics to the soil mixture. The USCS is based on those characteristics of the soil that indicate how it will behave as an engineering construction material. The following properties have been found most useful for classification purposes and form the basis of soil identification:

a. Percentage of gravel, sand, and fines.

b. Shape of the grain-size distribution curve.

c. Plasticity and compressibility characteristics.

In the USCS, the soil is given a descriptive name and a letter symbol indicating its principal characteristics. The USCS sheet, an auxiliary laboratory identification procedure, and characteristics pertinent to roads and airfields based on the USCS are shown in Figures 1, 2, and 3, respectively.

Field identification system

6. The primary factors considered for field identification of a soil are the same as those considered in classification of a soil according to the USCS: percentage of gravel, sand, or fines; the shape of the grain-size distribution curve; and the plasticity. The following field test procedures will help to estimate the identification of a material.

7. Grain-size identification. The approximate distribution of gravel, sand, and fines in a material can be determined from the following test procedure:

UNIFIED SOIL CLASSIFICATION
(Including Identification and Description)

Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights.)			Information Required for Describing Soil		
1	2		3	4	5			6		
Coarse-grained Soils More than half of material is larger than No. 200 sieve size.	Gravels More than half of coarse fraction is larger than No. 4 sieve size	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics. Give typical name; indicate approximate percentage of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses. Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).	Use grain-size curve in identifying the Fractions as given under field identification.	Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows:
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.					
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixture.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below)					
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below.)					
	Sands More than half of coarse fraction is smaller than No. 4 sieve size (For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size)	Clean sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines	Wide range in grain size and substantial amounts of all intermediate particle sizes.					
			SP	Poorly graded sands or gravelly sands, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing.					
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below)					
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below.)					
Fine-grained Soils More than half of material is smaller than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.					Identification Procedures on Fraction Smaller than No. 40 Sieve Size			For undisturbed soils add information on structure stratification, consistency in undisturbed and remolded states, moisture and drainage conditions. Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses. Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).		PLASTICITY INDEX
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)			
	Silts and Clays	Liquid limit is less than 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None			
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium			
			OL	Organic silts and organic silts clays of low plasticity.	Slight to Medium	Slow	Slight			
	Silts and Clays	Liquid limit is greater than 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium			
			CH	Inorganic clays of high plasticity, fat clays	High to very high	None	High			
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to mdeium			
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.					

(1) Boundary classification: Soils possessing characteristics of two groups are designated by combinations of group symbols. For examples GW-GC, well-graded gravel-sand mixture with clay binder. (2) All sieve si

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (crushing characteristics)

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air-drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt posses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness

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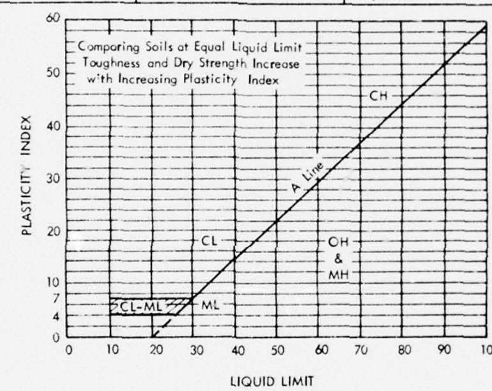
Figure 1. The Unified Soil Classification System (from MIL-ST

2

UNIFIED SOIL CLASSIFICATION
(Including Identification and Description)

...ld Identification Procedures ...ding particles larger than 3 in. ...ing fractions on estimated weights.)	Information Required for Describing Soil	Laboratory Classification Criteria			
5	6	7			
...in grain sizes and substantial ...of all intermediate particle sizes.	For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics.	Use grain-size curve in identifying the Fractions as given under field identification.	Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows: Less than 5% GW, GP, SW, SP. More than 12% GM, GC, SM, SC. 5% to 12% Borderline cases requiring use of dual symbols.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
...tly one size or a range of sizes with ...ntermediate sizes missing.				Not meeting all graduation requirements for GW	
...c fines or fines with low plasticity ...tification procedures see ML below)	Give typical name; indicate approximate percentage of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.			Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
...s (for identification procedures ...below.)				Atterberg limits above "A" line with PI greater than 7	
...in grain size and substantial amounts ...ntermediate particle sizes.				$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
...tly one size or a range of sizes with ...intermediate sizes missing.	Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength, well compacted and moist in place; alluvial sand; (SM).			Not meeting all graduation requirements for SW	
...ic fines or fines with low plasticity ...tification procedures see ML below)				Atterberg limits below "A" line or PI less than 4	Limits plotting in hatched zone with PI between 4 and 7 are borderline cases requiring use of dual symbols.
...es (for identification procedures ...below.)				Atterberg limits above "A" line with PI greater than 7	

Identification Procedures ...ction Smaller than No. 40 Sieve Size			Information Required for Describing Soil	Laboratory Classification Criteria
...th ...tics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)	For undisturbed soils add information on structure stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.	
...light	Quick to slow	None		
...o high	None to very slow	Medium	Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses.	
	Slow	Slight		
	Slow to none	Slight to medium		
...ery	None	High	Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).	
...o high	None to very slow	Slight to mdeium		PLASTICITY CHART
...ly identified by color, odor, spongy feel ...nd frequently by fibrous texture.				For laboratory classification of fine-grained soils

...symbols. For examples GW-GC, well-graded gravel-sand mixture with clay binder. (2) All sieve sizes on this chart are U.S. standard.

...NTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

...ed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, ...nded, simply remove by hand the coarse particles that interfere with the tests.

... (crushing characteristics)

...ing particles larger than No. 40 sieve size, mold a pat of soil to the ...cy of putty, adding water if necessary. Allow the pat to dry completely ..., sun, or air-drying, and then test its strength by breaking and crumbling ...the fingers. This strength is a measure of the character and quantity of ...idal fraction contained in the soil. The dry strength increases with ... plasticity.

...ngth is characteristic for clays of the CH group. A typical inor... ...posses only very slight dry strength. Silty fine sands and silts ...t the same slight dry strength, but can be distinguished by the feel ...dering the dried specimen. Fine sand feels gritty whereas a typical silt ...ooth feel of flour.

Toughness (consistency near plastic limit)

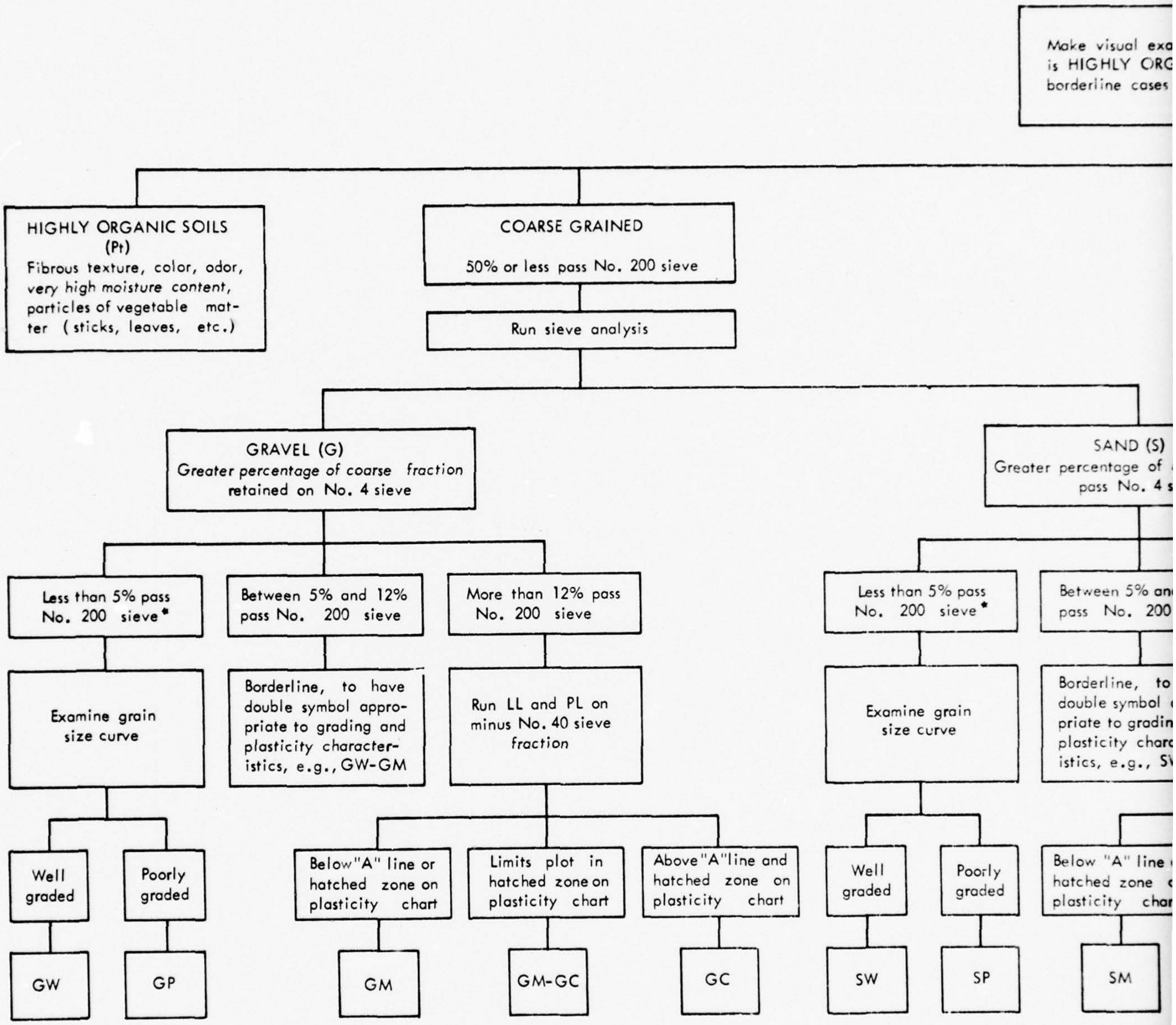
After particles larger than the No. 40 sieve size are removed, a specimen of soil about one-half inch in cube size, is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

...ed Soil Classification System (from MIL-STD-619B)



Note: Sieve sizes are U.S. Standard.

* If fines interfere with free draining properties use double symbol such as GW-GM, etc.

Figure 2. Auxiliary labora

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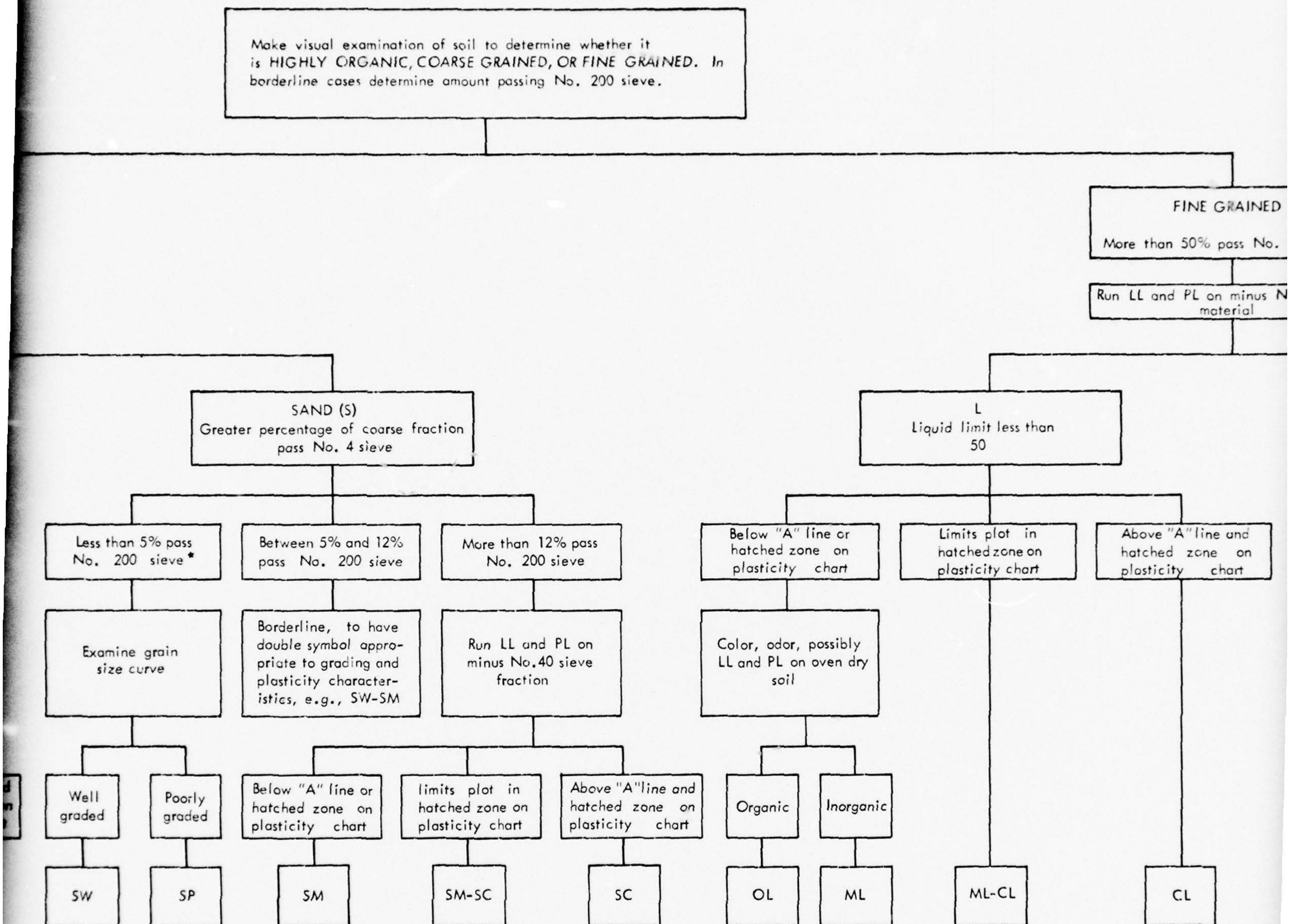
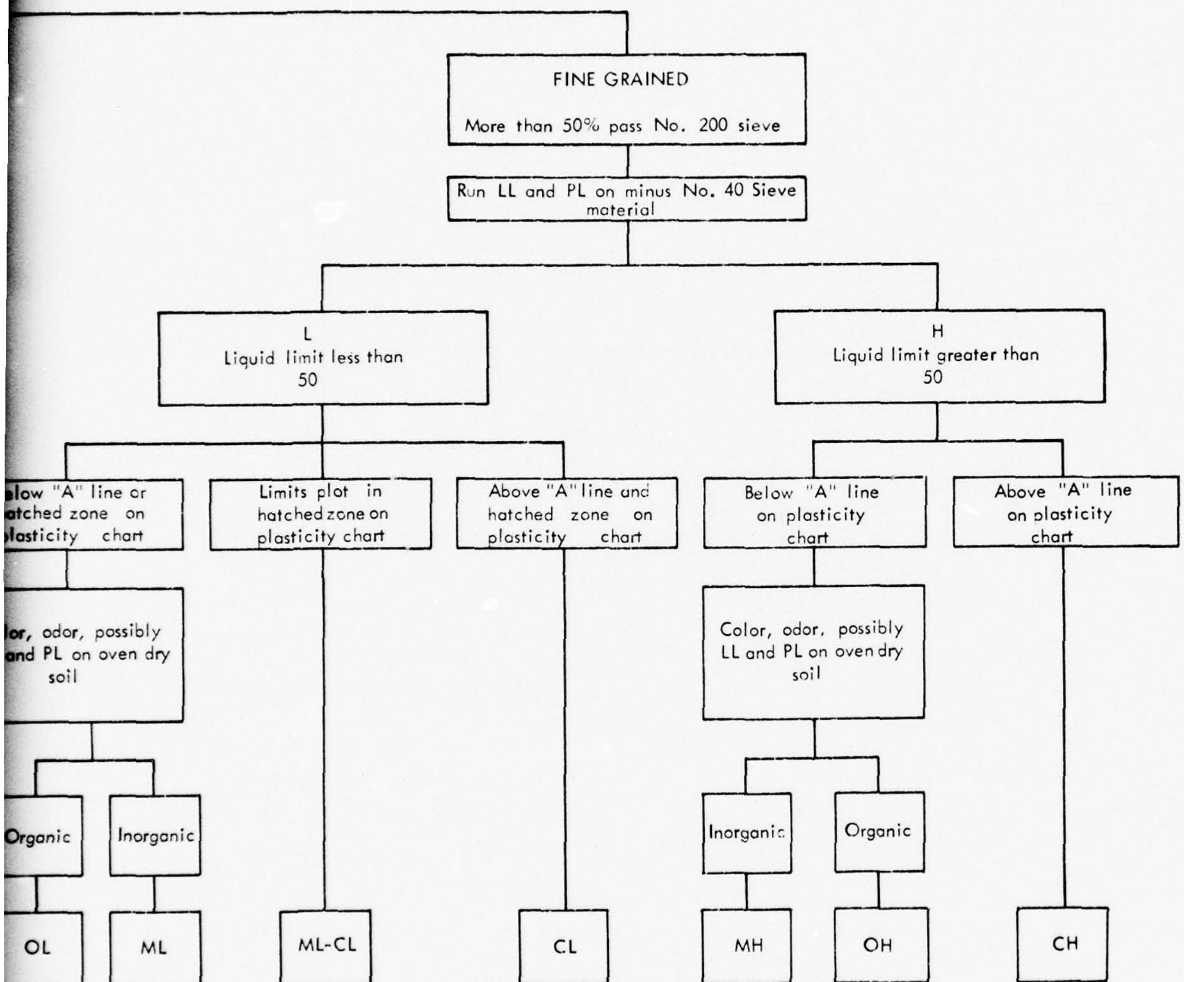


Figure 2. Auxiliary laboratory identification procedure (from MIL-STD-619B)



3

rom MIL-STD-619B)

Major Divisions (1)	(2)	Letter (3)	Symbol: Hatching (4)	Symbol: Color (5)	Name (6)	Value as Foundation When Not Subject to Frost Action (7)	Value as Base Directly under Bituminous Pavement (8)	Potential Frost Action (9)	Compressibil and Expansion (10)
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Good	None to very slight	Almost none
		GP		Red	Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Poor to fair	None to very slight	Almost none
		GM d		Yellow	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Fair to good	Slight to medium	Very slight
		GM u		Yellow	Silty gravels, gravel-sand-silt mixtures	Good	Poor	Slight to medium	Slight
		GC		Yellow	Clayey gravels, gravel-sand-clay mixtures	Good	Poor	Slight to medium	Slight
	SAND AND SANDY SOILS	SW		Red	Well-graded sands or gravelly sands, little or no fines	Good	Poor	None to very slight	Almost none
		SP		Red	Poorly graded sands or gravelly sands, little or no fines	Fair to good	Poor to not suitable	None to very slight	Almost none
		SM d		Yellow	Silty sands, sand-silt mixtures	Good	Poor	Slight to high	Very slight
		SM u		Yellow	Silty sands, sand-silt mixtures	Fair to good	Not suitable	Slight to high	Slight to medium
		SC		Yellow	Clayey sands, sand-clay mixtures	Fair to good	Not suitable	Slight to high	Slight to medi
FINE GRAINED SOILS	SILTS AND CLAYS LL < 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Fair to poor	Not suitable	Medium to very high	Slight to medi
		CL		Green	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Fair to poor	Not suitable	Medium to high	Medium
		OL		Green	Organic silts and organic silt-clays of low plasticity	Poor	Not suitable	Medium to high	Medium to hig
	SILTS AND CLAYS LL > 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitable	Medium to very high	High
		CH		Blue	Inorganic clays of high plasticity, fat clays	Poor to very poor	Not suitable	Medium	High
		OH		Blue	Organic clays of medium to high plasticity, organic silts	Poor to very poor	Not suitable	Medium	High
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	Not suitable	Not suitable	Slight	Very high

Notes:

1. Column 3, Division of GM, and SM groups into subdivisions of d and u are for roads and airfields only; subdivision is on basis of Atterberg limits; su plasticity index is 6 or less; the suffix u will be used when the liquid limit is greater than 28.
2. Column 7, values are for subgrades and base courses except for base course directly under bituminous pavement.
3. In column 8, the term "excellent" has been reserved for base materials consisting of high quality processed crushed stone.
4. In column 9, these soils are susceptible to frost as indicated under conditions favorable to frost action described in the text.
5. In column 12, the equipment listed will usually produce the required densities with a reasonable number of passes when moisture conditions and thicknes are listed, because variable soil characteristics within a given soil group may require different equipment. In some instances, a combination of two t
   a. Processed base materials and other angular materials. Steel-wheeled rollers are recommended for hard angular materials with limited fines or scree to degradation.
   b. Finishing. Rubber-tired equipment is recommended for rolling during final shaping operations for most soils and processed materials.
   c. Equipment size. The following sizes of equipment are necessary to assure the high densities required for airfield construction:
      Crawler-type tractor -- total weight in excess of 30,000 lb.
      Rubber-tired equipment -- wheel load in excess of 15,000 lb, wheel loads as high as 40,000 lb may be necessary to obtain the required densities f
      Sheepsfoot roller -- unit pressure (on 6- to 12-sq-in. foot) to be in excess of 250 psi and unit pressures as high as 650 psi may be necessary to should be at least 5 per cent of the total peripheral area of the drum, using the diameter measured to the faces of the feet.
6. Column 13, unit dry weights are for compacted soil at optimum moisture content for modified AASHO compactive effort.

Figure 3. Characteristics pertinent to roads and airfields base

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	Value as Foundation When Not Subject to Frost Action (7)	Value as Base Directly under Bituminous Pavement (8)	Potential Frost Action (9)	Compressibility and Expansion (10)	Drainage Characteristics (11)	Compaction Equipment (12)	Unit Dry Weight Lb Per Cu Ft (13)	Field CBR (14)	Subgrade Modulus k_s Lb Per Cu In. (15)
s	Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	125-140	60-80	300 or more
nd	Good to excellent	Poor to fair	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment, steel-wheeled roller	110-130	25-60	300 or more
	Good to excellent	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tired equipment, sheepsfoot roller; close control of moisture	130-145	40-80	300 or more
	Good	Poor	Slight to medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40	200 to 300
	Good	Poor	Slight to medium	Slight	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	120-140	20-40	200-to 300
ds,	Good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	110-130	20-40	200 to 300
	Fair to good	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired equipment	100-120	10-25	200 to 300
	Good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired equipment sheepsfoot roller; close control of moisture	120-135	20-40	200 to 300
	Fair to good	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	105-130	10-20	200 to 300
	Fair to good	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired equipment, sheepsfoot roller	105-130	10-20	200 to 300
ds,	Fair to poor	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired equipment, sheepsfoot roller; close control of moisture	100-125	5-15	100 to 200
	Fair to poor	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired equipment, sheepsfoot roller	100-125	5-15	100 to 200
lays	Poor	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired equipment, sheepsfoot roller	90-105	4-8	100 to 200
	Poor	Not suitable	Medium to very high	High	Fair to poor	Sheepsfoot roller	80-100	4-8	100 to 200
ty,	Poor to very poor	Not suitable	Medium	High	Practically impervious	Sheepsfoot roller	90-110	3-5	50 to 100
	Poor to very poor	Not suitable	Medium	High	Practically impervious	Sheepsfoot roller	80-105	3-5	50 to 100
ils	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical	-	-	-

oads and airfields only; subdivision is on basis of Atterberg limits; suffix d (e. g., GMd) will be used when the liquid limit is 28 or less and the
is greater than 28.
ctly under bituminous pavement.
ng of high quality processed crushed stone.
favorable to frost action described in the text.
with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipment
require different equipment. In some instances, a combination of two types may be necessary.
s are recommended for hard angular materials with limited fines or screenings. Rubber-tired equipment is recommended for softer materials subject

shaping operations for most soils and processed materials.
he high densities required for airfield construction:

as high as 40,000 lb may be necessary to obtain the required densities for some materials (based on contact pressure of approximately 65 to 150 psi).
ses of 250 psi and unit pressures as high as 650 psi may be necessary to obtain the required densities for some materials. The area of the feet
using the diameter measured to the faces of the feet.
for modified AASHO compactive effort.

ics pertinent to roads and airfields based on USCS (from MIL-STD-619B)

a. Separate gravel (material retained on No. 4 sieve).

(1) Select a random but typical specimen of soil.

(2) Remove from specimen all particles larger than 1/4 in.* in diameter.

(3) Estimate percent gravel by weight.

b. Sedimentation test. Determine percent sand (material passing No. 4 sieve and retained on No. 200 sieve) and percent fines (material passing No. 200 sieve).

(1) Place specimen (less gravel) in canteen cup and fill with water.

(2) Shake mixture vigorously.

(3) Allow mixture to stand for 30 sec to settle out sand particles.

(4) Pour off water containing the suspended fines into another container.

(5) Repeat steps b(2)-(4) until water poured off is clear.

(6) Dry the soil left in cup (sand).

(7) Estimate percent sand by weight.

(8) Dry the soil left in the second container and estimate percent fines by weight.

8. Distribution of grain sizes. After an estimate of the particle sizes has been made, the coarse-grained particles should be classified as either well graded or poorly graded. A good distribution of all sizes without too much or too little of any size means that the soil is well graded. Overabundance or lack of a particular size means that the material is poorly graded.

9. Plasticity. Plasticity can be estimated from the strength of an air-dried specimen. The specimen is prepared by first removing all particles coarser than a No. 40 sieve or anything larger than a grain of sugar and then molding a cube at the consistency of stiff putty, adding water if necessary. The cube is dried in air or sunlight and then crushed between the fingers. The ease or difficulty with which the cube crushes between the fingers indicates its plasticity. The listing below can be used as a general guide in estimating the plasticity:

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

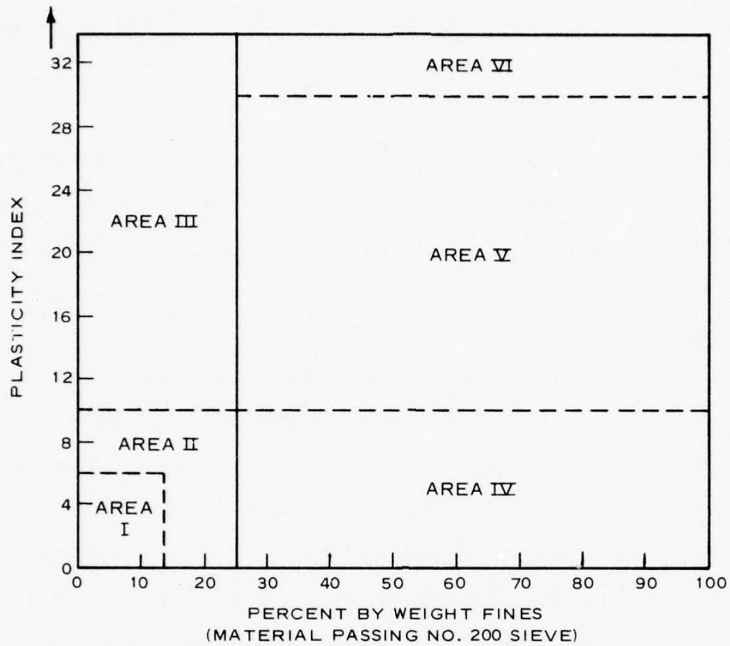
Term	Plasticity Index Range	Reaction to Crushing Between Fingers
Nonplastic	0 to 3	Falls apart easily
Slightly plastic	4 to 8	Easily crushed
Medium plastic	9 to 30	Difficult to crush
Highly plastic	31 or more	Impossible to crush

10. Density. The compaction of soils for roads and airfields requires that a high density be attained at the time of construction. The density or degree of compaction for coarse-grained soils may be estimated from the ease with which a rod penetrates the soil or from the data shown below:

Term	Relative Density Percent	Field Test
Loose	0 to 50	Easily penetrated with 1/2-in. reinforcing rod pushed by hand
Firm	50 to 70	Easily penetrated with 1/2-in. reinforcing rod driven with 5-lb hammer
Dense	70 to 90	Penetrated 2 ft with 1/2-in. reinforcing rod driven with 5-lb hammer
Very dense	90 to 100	Penetrated only a few inches with 1/2-in. reinforcing rod driven with 5-lb hammer

Procedure for Selecting Methods of Using In-Place Soils

11. The following procedure is presented to give general guidance in selecting a method to improve the physical properties of in-place soils so that they will be suitable for construction purposes. This procedure is based on the type of material encountered; therefore, it is required that the material first be identified either by the USCS or by a field identification system. After the soil has been classified, a stabilization method can be selected by use of Figure 4. This figure is subdivided using Atterberg limits and sieve analysis, which are determined or estimated during the identification of the soil. Two or more



AREA	TYPE OF STABILIZATION RECOMMENDED	REMARKS OR RESTRICTIONS
I	A. MECHANICAL	LIQUID LIMIT LESS THAN 25
	B. BITUMINOUS	
	C. PORTLAND CEMENT	
II	A. BITUMINOUS	
	B. PORTLAND CEMENT	
III	A. PORTLAND CEMENT	
	B. LIME	
IV	A. PORTLAND CEMENT	
	B. MESL	50 PERCENT OR MORE BY WEIGHT PASSES NO. 200 SIEVE
	C. SURFACE WATERPROOFING	50 PERCENT OR MORE BY WEIGHT PASSES NO. 200 SIEVE
V	A. LIME	
	B. PORTLAND CEMENT	
	C. BITUMINOUS	
	D. MESL	50 PERCENT OR MORE BY WEIGHT PASSES NO. 200 SIEVE
	E. SURFACE WATERPROOFING	50 PERCENT OR MORE BY WEIGHT PASSES NO. 200 SIEVE
VI	A. PORTLAND CEMENT	
	B. LIME	
	C. MESL	

Figure 4. Selection of stabilization method

methods are recommended for each subdivision. The decision as to which method to use will depend on the materials and equipment available and the weather conditions. If chemical stabilization is selected, a procedure is also presented to determine the range of chemical additives (lime, cement, or bitumen) required to sufficiently stabilize the material.

12. The following paragraphs describe each of the methods considered, suitable soils recommended for the respective methods, and procedures to determine the quantity of chemical additive required, if applicable.

Mechanical stabilization

13. Mechanical stabilization produces an interlocking of soil-aggregate particles. It is important that the grading of the soil-aggregate mixture be such as to produce a dense mass when compacted. Depending on the gradation of the material, mechanical stabilization can be accomplished either by uniformly mixing the material and then compacting the mixture or by the blending of additional fines or aggregates prior to compaction to form a uniform well-graded, dense soil-aggregate mixture after compaction. Pit-run or crushed aggregate can be added to the soil if it is deficient in coarse-grained materials. For best results, a well-graded, angular-shaped, sound aggregate should be used. If the soil-aggregate mixture is well graded, the quantity of fines should be kept below 5 percent for natural gravels with maximum aggregate size about 3/4 to 1 in., below 9 percent for crushed rock of the same gradation, and below about 14 percent for sand. The physical properties of the soil binder (material passing the No. 40 sieve) have a great effect on the stability of the interlocking soil-aggregate particles. Therefore, the liquid limit of the binder should be 25 percent or less, and the plasticity index should be not greater than 6 percent. These requirements may be lowered to a liquid limit of 45 percent and a plasticity index of 15 for emergency and minimum operational airfields when good drainage is provided. A rough method of determining if a material has the desired properties for a binder is to pat a wetted sample in the palm of the hand. If the sample will compact into a

dense cake that cannot be readily penetrated with a blunt stick the size of a pencil or if it will retain a definite shape after drying, the material is suitable for use as a binder.

Chemical stabilization

14. Lime. Experience has shown that lime will react with medium-, moderately fine-, and fine-grained soils to produce decreased plasticity, increased workability, reduced swelling, and increased strength. Lime-stabilized soil can be satisfactorily used as base course, subbase, or subgrade, depending on the characteristics of the soil being treated.

15. Lime is generally used in the stabilization of clay soils or gravels with clay binder material. In small quantities, it is very effective with clay-gravel mixes. Soils classified according to the USCS as CH, CL, MH, SC, GC, SW-SC, SP-SC, and GW-GC should be considered potentially capable of being stabilized with lime. The use of lime alone is not recommended for sandy soils.

16. Hydrated lime or quicklime may be used as the stabilizing agent, depending on availability of the type of lime and construction equipment. The reaction of quicklime with soils is similar to that of hydrated lime; however, hydrated lime is easier and safer to handle than quicklime. Quicklime can cause burns and irritations to workmen and should be used with caution. Quicklime gives off heat during hydration that produces a drying effect. Hence, the application of quicklime to areas that are unstable because of excessive moisture may actually dry the soil and allow construction work to proceed readily.

17. Generally, 4 to 6 percent lime by weight is required to achieve full stabilization for fine-grained soils, and 2 to 4 percent is required for granular soils. Figure 5 presents a general guide for determining the lime percentage based on minimum testing. This method is based on the percent soil binder and the plasticity index of the soil to be treated, which are determined during the identification of the soil.

18. Cement. Soil-cement is a uniform mixture of controlled proportions of pulverized soil, moisture, and portland cement compacted to form a stable foundation layer. Portland cement should be used only

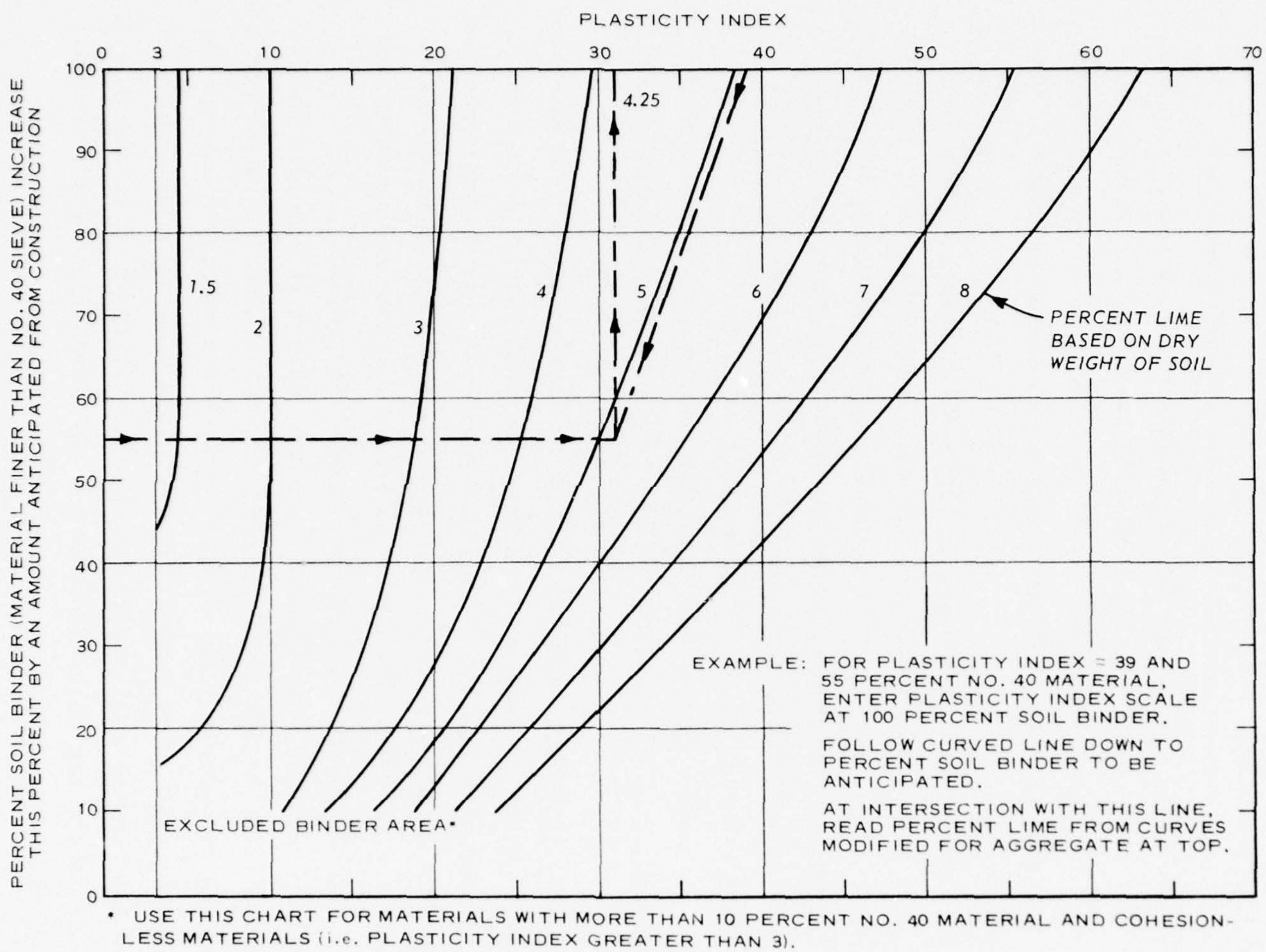


Figure 5. Recommended amounts of lime for stabilization (from American Association of State Highway Officials Designation: T 220-66)

with soils that can be thoroughly pulverized. In general, the in-place soil which is to be stabilized should have a plasticity index of less than 30, and, for coarse-grained materials, the percent passing the No. 4 sieve should be greater than 45 percent.

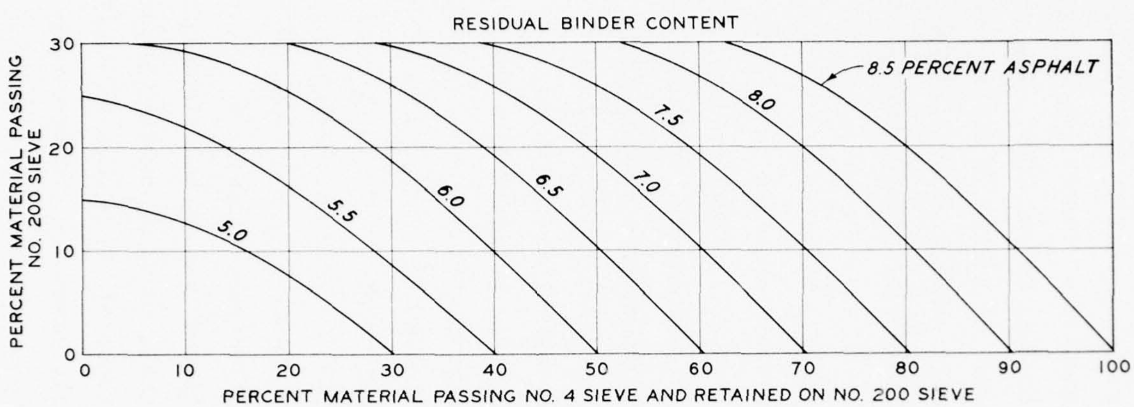
19. The principal factor affecting the quantity of cement required to stabilize a soil is its classification. Table 1 shows the approximate quantity of cement required to stabilize various soils classified according to the USCS. These values are approximate and should be treated as such. In areas where a particular type soil has been successfully stabilized with different cement contents than those suggested in Table 1, it is recommended that such experience be taken into account.

20. Bitumen. Bituminous stabilization is the process in which soil and bitumen are combined to achieve a more stable mass. The majority of bituminous soil stabilization is performed with asphalt cement, cutback asphalt, and asphalt emulsion. However, it should be noted that stabilization with asphalt cements is usually not considered in a TO due to the lack of central batch plants and other specialized equipment required for use with asphalt cements. As a general rule, only those soils which can readily be pulverized by mix-in-place construction equipment are satisfactory for bituminous stabilization. Soils having more than 30 percent by weight of particles passing the No. 200 sieve and/or a plasticity index greater than 10 generally are not adaptable to bituminous stabilization. Soils classified as SW, SP, SW-SM, SP-SM, SW-SC, SP-SC, SM, SC, SM-SC, GW, GP, GW-GM, GP-GM, GW-GC, GP-GC, GM, GC, and GM-GC can be effectively stabilized with bituminous materials provided the above-mentioned grading and plasticity requirements are met.

21. Asphalt cements, cutback asphalts, and emulsified asphalts are suitable types of bituminous materials for soil stabilization. The grade of asphalt cement can be determined from Figure 6a depending on the pavement temperature index. The quantity of asphalt cement can be determined on a preliminary basis from Figure 6b. This preliminary content is based on aggregate shape and surface textures. The mixture should be compacted by some means to insure that excess asphalt is not

CLIMATIC ZONES	ASPHALT GRADE, PENETRATION
ARCTIC	100 TO 120
TEMPERATE	85 TO 100
TROPIC	60 TO 70
DESERT	40 TO 50

a. DETERMINATION OF ASPHALT GRADE FOR EXPEDIENT CONSTRUCTION



b. SELECTION OF ASPHALT CEMENT CONTENT

Figure 6. Selection of grade and quantity of asphalt cement

present in the mix. Excess asphalt will be evident on the top, sides, and bottom of the specimen if it exists.

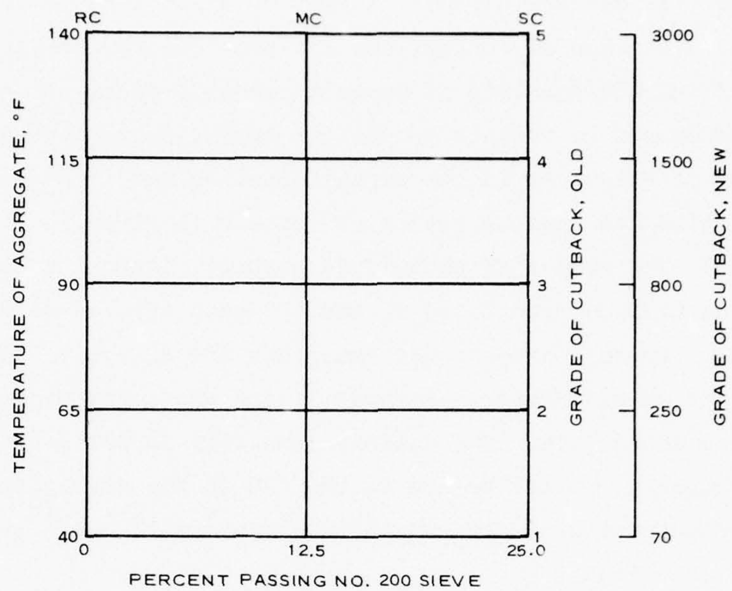
22. If cutback asphalt is chosen to stabilize a native material, the type and grade of cutback asphalt required can be determined from Figure 7 and the quantity of asphalt cement from Figure 6b. To determine the amount of cutback asphalt to apply, a correction for the quantity of volatiles in the asphalt must be made. A rough estimate of the volatiles in various grades of cutback is given in Figure 7b.

23. The grades of emulsified asphalt required to stabilize a soil can be determined from Table 2, and the quantity can be determined from Table 3. Cationic and anionic emulsions are effective in stabilizing many types of aggregates. However, there are a few exceptions that should be noted: (a) if a cationic emulsion is being used and it breaks up too quickly, it may be due to the CaO in the aggregate; and (b) a high concentration of SiO_2 in the aggregate will cause stripping of anionic emulsions.

Waterproofing techniques

24. A road or airfield can be waterproofed satisfactorily by one of the following two methods based on the drainage characteristics of the facility. The first method consists of waterproofing the surface of the road or airfield with a prefabricated or formed-in-place membrane. A surface membrane will adequately waterproof a facility that is well drained and requires protection from only rainfall. The second method consists of encasing a compacted layer of soil in a waterproof membrane, i.e., MESL construction. In areas where soils must be protected from moisture intrusion due to rainfall and capillary migration, MESL-type construction should be used to waterproof the facility.

25. Surface membrane. Experience has shown that compacted fine-grained soil exhibits high strength that can be maintained if it is kept dry. Surface membranes such as polypropylene-asphalt and prefabricated neoprene-coated nylon fabric membranes have been developed for application to roadways and airfields to protect the compacted subgrade from intrusion of rainwater. The soil being protected by these membranes should contain 50 percent or more fines and be compacted to maximum



a. TYPE OF CUTBACK

EXAMPLE: FOR AGGREGATE TEMPERATURE OF 100 F AND 10 PERCENT PASSING NO. 200 SIEVE, USE MC 800 CUTBACK.

TYPE	COMPONENTS		PERCENT OF TOTAL VOLUME FOR CITED GRADES				
	BASE	SOLVENT	30	70	250	800	3000
RAPID CURING (RC)	ASPHALT CEMENT		-	65	75	83	87
		GASOLINE OR NAPHTHA	-	35	25	17	13
MED CURING (MC)	ASPHALT CEMENT		54	64	74	82	86
		KEROSENE	46	36	26	18	14
SLOW CURING (SC)	ASPHALT CEMENT		-	50	60	70	80
		FUEL OIL	-	50	40	30	20

b. ASPHALT CUTBACK COMPOSITION

Figure 7. Selection of type and grade of cutback asphalt

density at or slightly less than optimum moisture content prior to installing the waterproofing surface. In-place soils containing large sharp aggregates should not be waterproofed with these types of surface membranes because the aggregate tends to puncture the membrane under traffic.* Soils classified as CL, CH, ML, and MH according to the USCS are generally regarded as acceptable for waterproofing with a surface membrane and can be expected to withstand rubber-tired traffic. The drainage conditions for any facility which is to be waterproofed with a surface membrane should be such as to isolate the facility from external sources of water.

26. Generally there are two types of membranes that can be installed as surface waterproofing material for fine-grained soils. One type is called a polypropylene-asphalt membrane and is formed by applying emulsified asphalt to the surface of the soil layer, placing the polypropylene material, applying a second coat of asphalt, and then placing a blotter layer of sand. This type of membrane requires an asphalt distributor during construction and will perform satisfactorily under rubber-tired vehicular traffic. The second type surface membrane considered is a prefabricated neoprene-coated nylon fabric. This type of membrane is fabricated in two- and four-ply thicknesses and is designated as T17 and XW18, respectively. T17 surfacing is adequate for operations of light fixed-wing aircraft, and XW18 membrane will withstand the braking action of C-130 aircraft. Tracked vehicles will tear both the formed-in-place and prefabricated membranes.

27. MESL. A MESL base course is especially applicable in areas where only fine-grained soils are available and in low-lying areas where groundwater intrusion into the foundation materials is prevalent during the wet seasons. The MESL concept involves complete encasement of a compacted layer of fine-grained soil by a lower and upper waterproof membrane. The construction of a MESL base course consists of removing the design thickness of soil from the roadbed and stockpiling it,

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* Coarse-grained soils and soils containing sharp aggregates should be waterproofed by applying either single or multiple asphalt surface treatments.

placing the lower membrane, replacing the soil on the lower membrane, compacting the soil layer, and then installing the upper wearing membrane. The upper polypropylene-asphalt membrane is capable of supporting limited rubber-tired traffic operations and is formed as described in the previous paragraph. More detailed instructions for MESL construction are available in Instruction Reports S-71-1* and S-69-5.**

28. Precautions should be taken during the construction of a MESL base course to (a) schedule the construction period when the weather conditions will remain relatively dry and (b) prevent puncturing the lower membrane which covers the bottom and sides of the excavation during compaction of the soil layer. Precautions should also be taken after construction to prevent tears in the upper membrane which will probably occur under traffic of tracked vehicles or from sliding locked wheels of heavy trucks. Tears in the upper membrane necessitate immediate repair. If water enters the soil layer through tears in the upper membrane, the lower and upper membranes act as barriers and hold the water within the encapsulated soil. The water then tends to migrate within the soil layer, causing the soil to lose strength. Unless the wet soil is replaced and the upper membrane repaired, the water will continue to infiltrate and weaken larger areas. Traffic over a weakened area will form ruts and may cause failure of the upper membrane.

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* A. H. Joseph and S. L. Webster, "Techniques for Rapid Road Contruction Using Membrane-Enveloped Soil Layers," Instruction Report S-71-1, Feb 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

** C. D. Burns and W. N. Brabston, "Membrane-Enveloped Soil Layers as Base Courses for Airfields," Instruction Report S-69-5, Jun 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

PART III: THICKNESS DESIGN PROCEDURE

29. Design curves for forward area airfields and roads are shown in Figure 8. For each type of airfield, the controlling type of aircraft, typical gross weights, and design life or number of cycles (takeoffs and landings) are shown. One design curve based on 20×10^6 equivalent number of 18-kip, single-axle, dual-wheel applications is presented for forward area roads. Depending on the CBR of the unstabilized subgrade and on the type of facility, this design procedure enables determination of the thickness of overlying structures that must be constructed for each anticipated facility. It is recommended that all stabilized layers have a minimum thickness of 6 in. The design thicknesses are based on the recommended percentages of stabilizer or methods of stabilization determined from the previous part of this report. The curves indicate the total pavement thickness required on an unstabilized subgrade over a range of subgrade strength values. It should be noted that each curve terminates above a certain subgrade CBR. This is because design strength criteria for unsurfaced facilities indicate that a natural soil of or in excess of this approximate strength would be capable of sustaining the traffic volume required without the benefit of stabilization. These curves are intended to be used as guidance only and in no way should they supersede specific trial-proven experience or laboratory testing when either exists. In addition to the total thickness determined from this design procedure, a thin wearing course may be advisable to provide waterproofing or to minimize the effects of tire abrasion.

30. Use of these criteria can best be illustrated by examples. The following examples are presented in explanation of typical design situations:

a. Example 1.

(1) A unit is given the mission of constructing an airfield facility for the logistical support of an infantry division and certain nondivision artillery units. This facility will have to sustain takeoffs and landings of C-130 aircraft (gross weight of

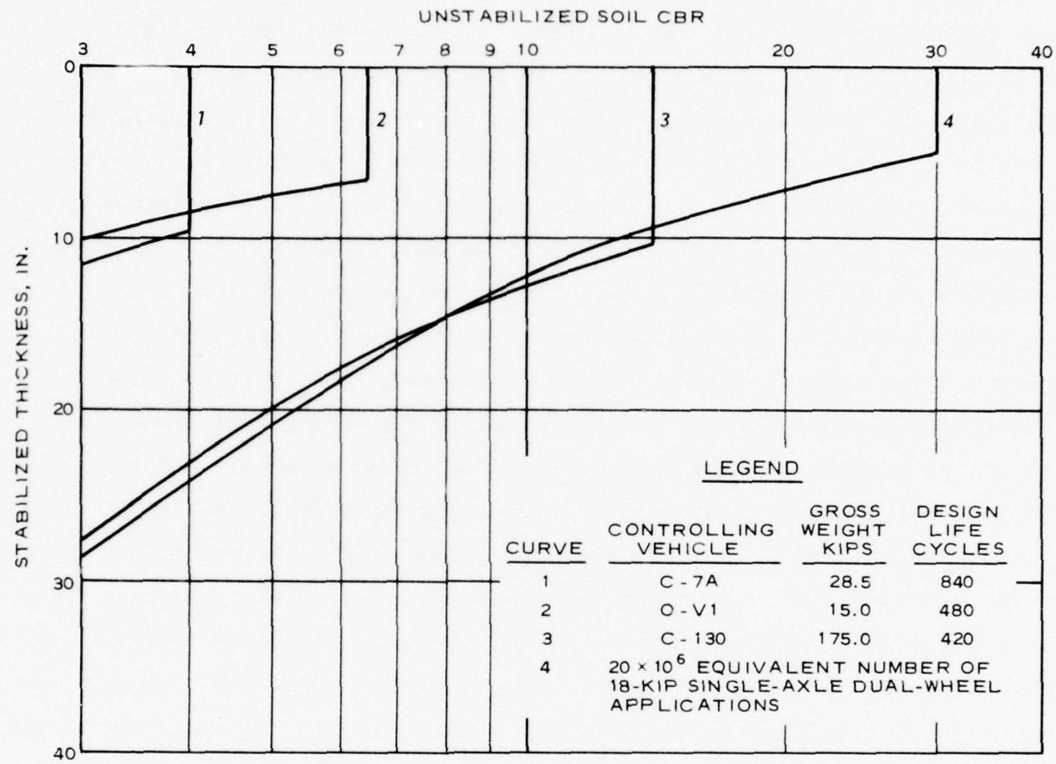

Figure 8. Road and airfield design curves for stabilized soils in forward areas

150,000 lb) along with smaller aircraft. Due to unsatisfactory soil strength requirements and availability of chemical stabilizing agents, stabilization is to be considered. This facility also will be a short-term field in the forward area and will be considered expedient design.

(2) A site reconnaissance and a few soil samples indicate the natural soil strength to be 8 CBR. Sieve analysis and Atterberg limits show 20 percent of the material passing a No. 200 sieve, 30 percent passing a No. 40 sieve, a plasticity index of 28, a liquid limit of 30, and 45 percent of the material being retained on a No. 4 sieve as being reasonably representative of the soil at the proposed site. The soil classifies as GC according to the USCS.

(3) Using this information, Figure 4 is entered, and it is determined that cement or lime is the proper agent.

(4) From Figure 5, a lime content of 3 percent is selected for this soil having a plasticity index of 28 and percent soil binder of 30. Results indicate that 3 percent lime will be adequate.

(5) Since the soil classifies as GC, from Table 1 an estimated cement content of 7 percent is selected.

(6) The characteristics of both additives are then reviewed, and, due to the predicted cool weather conditions, cement stabilization is chosen.

(7) The design thickness is then determined from Figure 8. For a subgrade strength of 8 CBR, a design thickness of 15 in. is determined.

b. Example 2.

(1) A unit is assigned the mission of quickly providing an expedient road between two organizational units. Only the in-place material can be stabilized. The preliminary site investigation indicates that the soil has a natural strength of 15 CBR, a liquid limit of 30, and a plasticity index of 15 and that 55 percent of the material passes the No. 200 sieve. The soil classifies as a CL material according to the USCS.

(2) Only cement, emulsified asphalt, and polypropylene are readily available. Due to 55 percent of the material passing the No. 200 sieve, bituminous stabilization is not considered. Therefore, either cement stabilization or MESL construction will be used, depending upon the equipment available and

predicted weather conditions during the construction period. If cement stabilization is selected, a cement content of 10 percent should be used as determined from Table 1. A design thickness of the stabilized material or MESL is then determined from Figure 8 to be 10 in.

c. Example 3.

(1) A unit is given the mission of providing a road between two organizational task forces. The preliminary site investigation indicates a soil strength of 10 CBR, 80 percent of the material passing the No. 4 sieve, 50 percent passing the No. 40 sieve, 20 percent passing the No. 200 sieve, and a plasticity index of 8.

(2) From Figure 4, it is determined that either cement or bitumen can be used to upgrade this material. However, only cutback asphalt is readily available.

(3) After the temperature of the in-place soil has been determined to be 110°F, an SC-800 cutback asphalt is selected from Figure 7a based on a temperature of 110°F and 20 percent passing the No. 200 sieve.

(4) An estimated asphalt content of 7.5 percent should be used as determined from Figure 6b.

(5) Since the estimated quantity of asphalt (7 percent) determined in step (4) does not include the solvent in the SC-800 cutback asphalt, a correction must be made. Figure 7b shows that an SC-800 cutback asphalt is approximately 70 percent asphalt cement and 30 percent fuel oil. Therefore, the quantity of cutback asphalt (SC-800) should equal the originally estimated quantity of asphalt cement (7.5 percent) plus 30 percent of this estimate or 7.5 + 2.25 percent, which equals 9.8 percent.

(6) A design thickness of 12 in. is then determined from Figure 8. This thickness is based on a subgrade strength of 10 CBR and the design curve presented for roads, Curve 4.

d. Example 4.

(1) A unit is to provide an expedient airfield capable of withstanding O-V1 aircraft traffic. The preliminary site investigation indicates that the soil classifies as GM according to the USCS and has a natural soil strength of 23 CBR and that drainage conditions are satisfactory. The extended weather forecast indicates that rain can be expected 50 percent of the time for the next 60 days.

(2) From a study of the design curve for O-V1 aircraft (Figure 8), it can be seen that a 23-CBR soil strength is adequate. However, a reduction in strength can be anticipated due to the predicted rainfall.

(3) A serviceable airfield can be constructed on this site and expected to remain operable during the predicted rainfall if (a) the site is shaped to the proper crown and grade, (b) an adequate drainage system is provided, and (c) the surface of the airfield is waterproofed.

(4) Because of the aggregate or coarse-grained natural soil, a single or multiple asphalt surface treatment should be applied to waterproof the airfield.

PART IV: CONSTRUCTION TECHNIQUES AND PROCEDURES

Mixing Methods

31. In general, the construction procedure for stabilizing soils after a method has been chosen consists of pulverizing the soil to the desired depth, adjusting the moisture content and adding the chemical stabilizing agent and/or required soil types, thoroughly mixing the added materials with the native soil, and compacting the uniform mixture to the desired density. The processes of pulverizing and mixing are the most important steps in the entire stabilization operation. Considerable care should be given to the selection of the appropriate equipment for these steps, and field personnel should be well versed in the proper operation of this equipment.

32. Both in-place and central-plant mixing operations can be used in soil stabilization construction. Central-plant mixing operations, either a continuous-flow type or a batch-type mixing plant, usually result in a more uniform and thoroughly mixed stabilized soil; however, the additional costs and equipment requirements often make central mixing impractical for TO construction. In-place mixing can be performed with one of the following types of equipment: traveling plants, rotary mixers, plows, or motor graders. A more uniform in-placed mixture can be obtained by use of either a windrow-type or a multiple-shaft traveling mixing machine; however, if this type equipment is not available, mixing can be adequately performed with several passes of a pulvimixer or plow or by working windrows back and forth with motor graders. The following paragraphs describe the general procedures for various in-place mixing methods.

Windrow-type traveling mixing machine

33. Prior to mixing, pulverized soil is placed in uniform windrows at predetermined intervals across a graded subgrade. The number and size of windrows needed depend on the width and depth of treatment and on the capacity of the mixing machine. After the windrows are formed, the stabilizing agent selected is applied to the top of the prepared

soil windrow in either bulk or bag form. The mixing machine then dry-mixes the soil and additive with the first few paddles in the mixing drum, and then a measured amount of water is added and mixed with the remaining paddles to complete mixing. The uniformly mixed windrow is then spread with a strike-off attached to the mixer or with a motor grader. After spreading, the material is ready for compaction.

Multiple-shaft
traveling mixing machine

34. The only preparation required before using this type of machine is shaping the native soil to approximate crown and grade. The required quantity of stabilizing additive should be placed either in bulk or bag and spread uniformly over the surface area prior to mixing. The mixing machine then moves forward pulverizing the soil and stabilizing agent to the desired depth. When the pulverized material enters the mixing chamber, water is added if needed, and the remaining rotors uniformly mix the soil, stabilizing agent, and water. The mixed material is left flat and on grade behind the mixing machine ready for compaction.

Pulvimixers and plows

35. Before mixing with pulvimixers or plows, the soil should first be scarified and pulverized and then shaped to the desired grade and crown. Moisture should be added to the soil if needed during scarification and pulverization. The stabilizing agent is then placed in bulk or by bag and spread evenly ahead of the mixing operation. If bagged material is being used, it should be spread in rows perpendicular to the direction of travel of the mixing machine. The pulvimixer or plow then mixes the soil and stabilizing agent as it moves forward. Additional water can be applied ahead of the mixing operation either by water pressure distributors or by the spray bar mounted in the mixing chamber on some pulvimixers. Usually several passes of these types of mixing machines are required to obtain a uniform mixture. Mixing should be continued until a uniform mixture is obtained to the desired depth. After mixing, the material should be regraded to the desired crown and grade and then compacted.

Blade mixing

36. The blade mixing method consists of placing the material to be mixed in windrows and then placing the stabilizing agent, if required, uniformly along the windrows. After the stabilizing agent has been spread evenly on the windrows, it is mixed with the soil by moving the windrows from side to side by successive cuts with a motor grader blade. Several graders can operate one behind the other if the equipment is available. It should be noted that the bitumen should be applied with a bituminous distributor in two or more equal applications to the flattened windrows if this method of mixing is used for bituminous stabilization. Each application is usually from 0.3 to 0.5 gal per square yard. After the soil, aggregate, and stabilizing agent have been thoroughly mixed, the mix should be bladed into a single windrow at or near the center of the area being stabilized. The windrow should then be turned not less than four complete turns from one side of the area to the other before it is bladed to grade and crown. After fine-blading, the mixed material is ready for compaction.

Compaction Methods

37. The stability of soils is increased by compaction, since compaction produces a denser mass and a greater interlocking of the soil particles. For cohesive materials, it is imperative that moisture be controlled. For a particular compaction effort, there will be a moisture content at which the greatest density will be obtained, which is known as the optimum moisture content. An easy way of determining approximately the optimum moisture content of a particular soil is to press a small quantity of the mixed material between the palms of both hands. If the material can be compressed into a firm, moist ball, the mixture is close to its optimum moisture content. For cohesionless materials, maximum density is obtained with the materials in a saturated condition at the start of compaction. The selection of compaction equipment depends on the type of material to be compacted. Pneumatic-tired and sheepsfoot rollers are best adapted to the compaction of

cohesive soils. Cohesionless soils can best be compacted by heavy tracked tractors, vibratory compactors, or pneumatic-tired rollers. Smooth, steel-wheeled rollers may be used as necessary to maintain a smooth surface during compaction and after finishing operations. Figure 3 indicates types of compaction equipment applicable for different types of soil classified according to the USCS. Ideally, the best roller for any particular job is the one which will achieve the desired compaction with the least amount of work. Usually, the required compaction can be obtained with a maximum of 6 to 10 complete coverages of the compaction equipment.

38. Sheepsfoot rollers can generally be used for initial compaction on all but the most granular soils. The material being compacted must be in a loose condition at the start of compaction so that the feet will compact the bottom material. The thickness of material being compacted with a sheepsfoot roller should never be in excess of the length of the shank. If the roller is properly loaded so as not to exceed the ultimate bearing capacity of the materials being compacted, the roller feet should penetrate into the soil as much as 4 or 5 in. on the first pass over a loose lift; but, as the soil densifies under the roller, the roller should begin to walk out, and, by the end of three or four coverages, the roller should walk out to within about 1 in. of the surface of the material being compacted. However, if the roller is too heavy or the soil too wet to develop the necessary bearing capacity, the roller feet will continue to penetrate into the soil to an appreciable depth. If the roller continues to penetrate deeply into the soil after several passes, the weight of the roller should be decreased or the material dried slightly. After the material has been thoroughly compacted to the desired depth with a sheepsfoot roller, the compacted surface should be fine-bladed with a motor grader and then compacted with either a rubber-tired or steel-wheeled roller.

39. Pneumatic-tired rollers vary in gross weight from 2,000 to 200,000 lb and are either self-propelled or towed type. The roller most used in soil compaction is probably a 50-ton roller which is equipped with four wheels abreast. The weight of this roller can be varied from

about 23 tons empty to 50 tons when fully ballasted with wet sand. This type of roller is effective in compacting both cohesive and cohesionless materials. If large ruts occur during compaction, the contact pressure of the roller is exceeding the bearing capacity of the soil and should be corrected by adjusting either the gross weight of the roller or the tire pressure. The desired density should be obtained after 4 to 8 coverages of the roller. A 50-ton, four-wheeled roller is capable of obtaining adequate densities up to depths of 12 in. The compaction effort of light rubber-tired rollers (10 tons or less with 7 to 13 wheels) is effective to a depth of only about 6 in.

40. Crawler-type tractors and vibratory compactors can be used to compact cohesionless materials. The shaking action or vibration of this type equipment reorients the grain particles into a more dense structure. Vibratory compactors are effective in compaction to depths of 2 to 4 ft in cohesionless materials, and crawler-type tractors should not be used on layers thicker than about 6 in.

Details of Construction Procedures and Techniques

41. Military engineers faced with expedient construction in a TO usually are faced with limited equipment. Knowledge of the equipment required for a particular construction operation and of the type of equipment that can be substituted may be a valuable planning tool, not only in anticipating the type of equipment necessary to perform a task but also in determining a method of improving the stength characteristics of soils. Most of the stabilization methods presented in this report require thorough mixing of the in-place material and an additive. Central-plant mixing operations usually result in a more uniform and thoroughly mixed stabilized soil; however, central-plant mixing is usually impractical for TO construction and in-place mixing is performed. Typical in-place construction operations consist of the following steps:

a. Preparation of the construction area (Figure 9).

b. Spreading of the stabilizer (Figure 10).

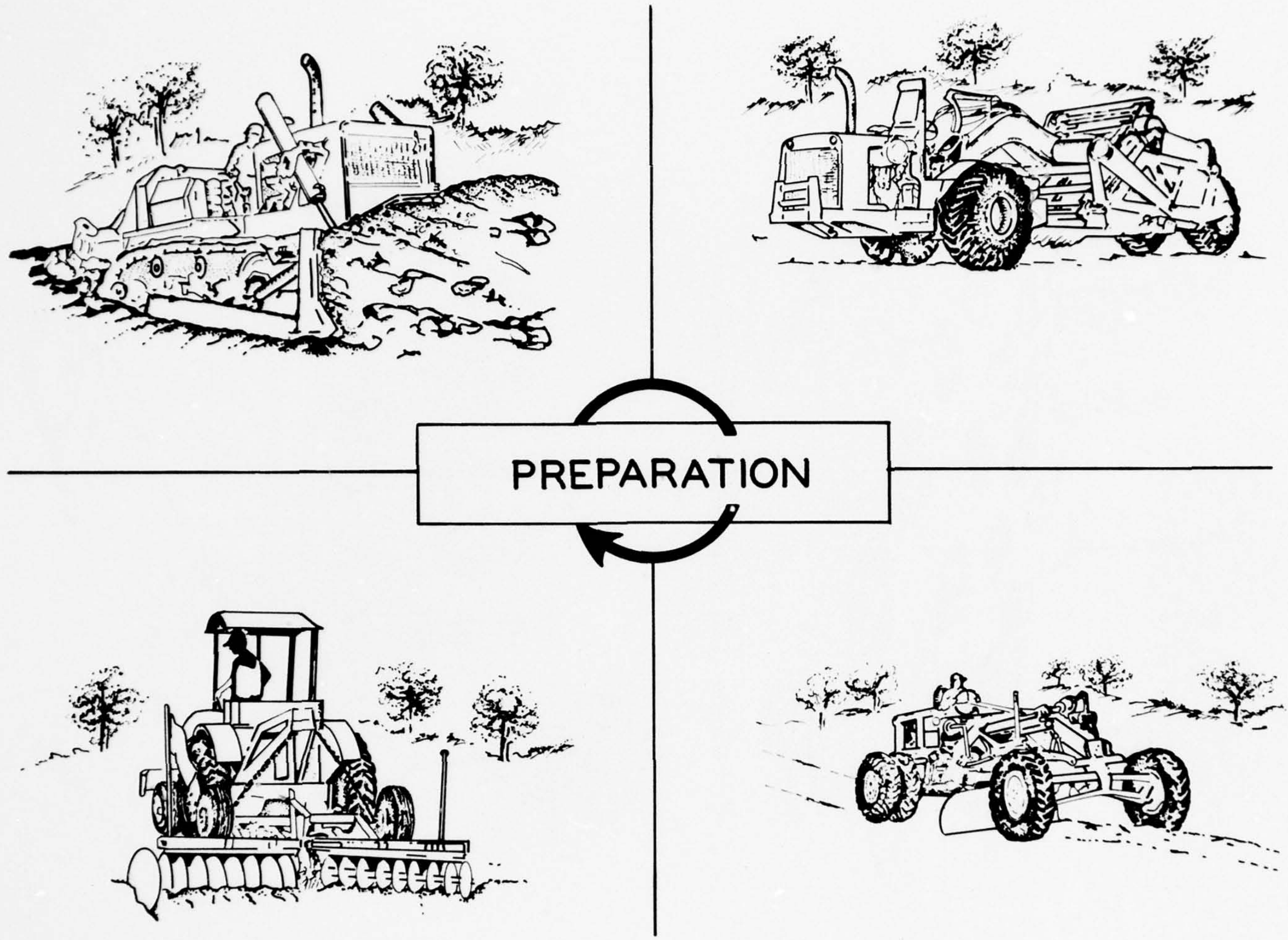

Figure 9. Preparation of surface for in-place stabilization

Figure 10. Spreading the stabilizer

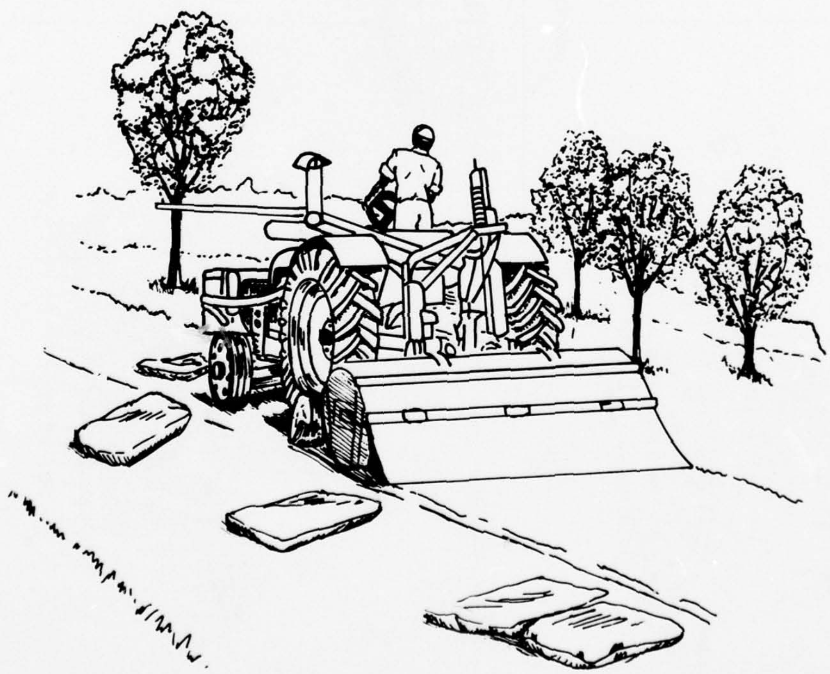

Figure 11. Mixing the stabilizer

c. Mixing and watering (Figure 11).

d. Compaction (Figure 12).

e. Curing (Figure 13).

Detailed construction steps for in-place mechanical, chemical, and waterproofing stabilization methods are included below.

Mechanical stabilization

42. Preparation.

a. Shape area to crown and grade.

b. Scarify, pulverize, and adjust moisture content of soil, if necessary. All deleterious material such as stumps, roots, turf, etc., should be removed.

c. Reshape to crown and grade.

43. Addition of deficient materials (if necessary). Use one of the following methods:

a. Distribute evenly by means of an approved stone spreader.

b. Use spreader boxes behind dump trucks.

c. Tailgating each measured truck, load to cover a certain length.

d. Dump in equally spaced piles, and then form into windrows with a motor grader prior to spreading.

44. Mixing.

a. Add water if required to obtain a moisture content of about 2 percent above optimum, and mix with either a traveling mixer, pulvimixer, blade, scarifier, or plow.

b. Mixing should continue until the soil and aggregate particles are in a uniform well-graded mass.

c. Blade to crown and grade (if needed).

45. Compaction.

a. Initiate as soon after mixing as possible to prevent loss of moisture by evaporation.

b. Use sheepsfoot roller, pneumatic-tired roller, or crawler-type tractor; finish with steel-wheeled rollers or light-weight pneumatic-tired rollers.

Lime stabilization

46. Preparation.

a. Shape surface to crown and grade.

b. Scarify to specified depth.

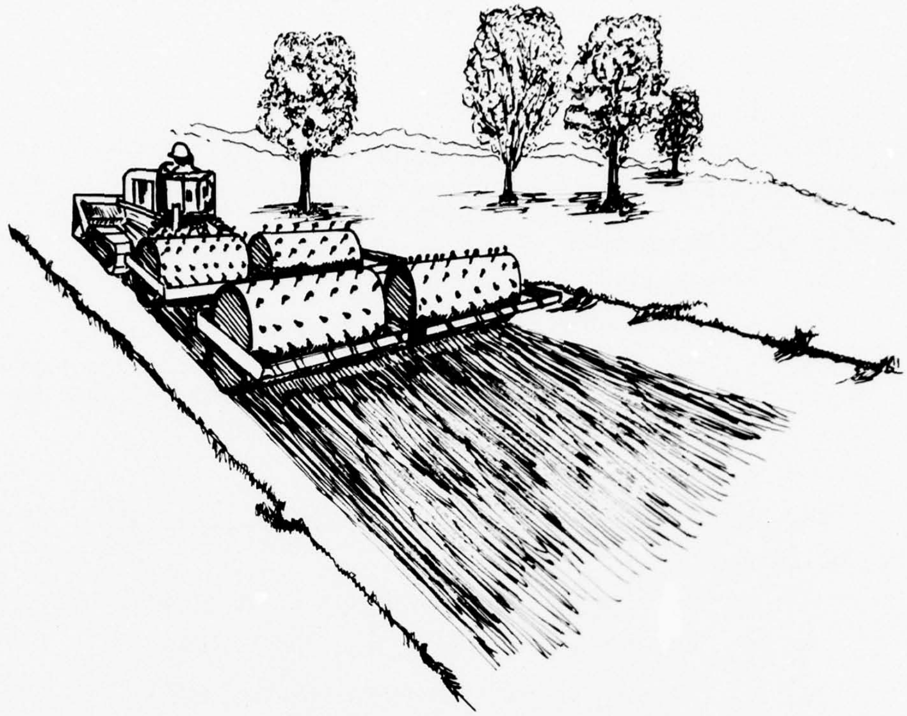

Figure 12. Compaction of stabilized material

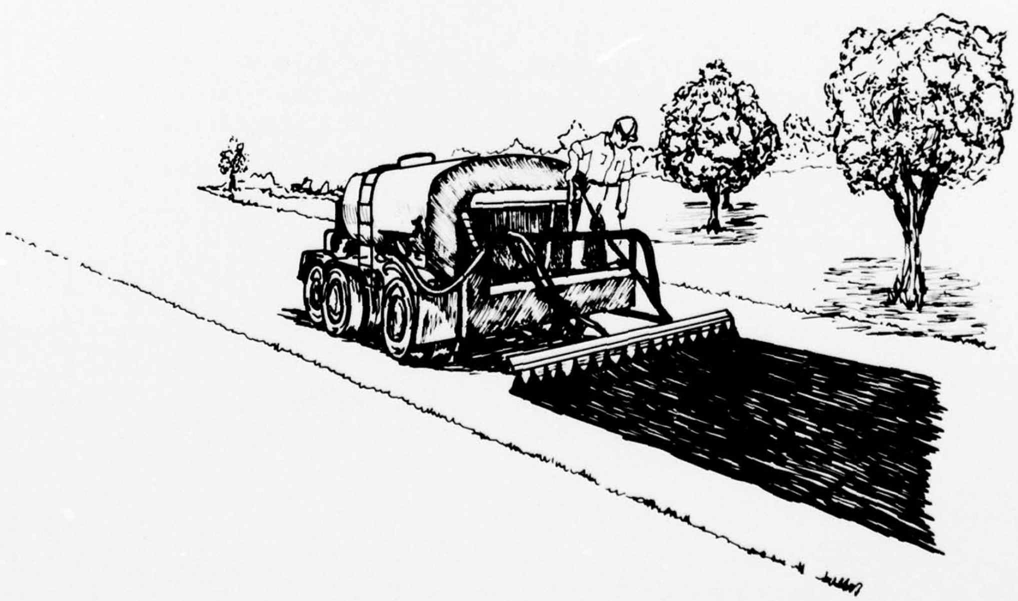

Figure 13. Applying asphalt membrane to prevent moisture evaporation from stabilized layer during curing

c. Partially pulverize soil.

d. Remove all deleterious materials such as stumps, roots, turf, etc., and soil-aggregate particles larger than 3 in.

47. Lime spreading. Select one of the following methods and use about one-half of the total lime required:

a. Spot paper bags of lime on the runway, empty the bags, and level the lime by rake or drag.

b. Apply bulk lime from self-unloading trucks (bulk trucks) or dump trucks with spreaders.

c. Apply the lime by slurry (1 ton of lime to 500 gal of water). The slurry can be mixed in a central plant or in a tank truck and distributed by standard water or asphalt tank trucks with or without pressure.

48. Preliminary mixing, watering, and curing.*

a. Mix lime and soil (pulverize soil to less than 2-in. particle size exclusive of any gravel or stone).

b. Add water. (Caution: The amount of water needs to be increased by approximately 2 percent for lime stabilization purposes.)

c. Mix the lime, water, and soil using rotary mixers (or blades).

d. Shape the lime-treated layer to the approximate section.

e. Compact lightly to minimize evaporation loss, lime carbonation, or excessive wetting from heavy rains.

f. Cure lime-soil mixture for 0 to 48 hr to permit the lime and water to break down any clay clods. For extremely plastic clays, the curing period may be extended to 7 days.

49. Final mixing and pulverization.

a. Add remaining lime by appropriate method.

b. Continue mixing and pulverization until all of the clods are broken down to pass a 1-in. screen and at least 60 percent of the material will pass a No. 4 sieve.

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* Lime stabilization of certain soils can be successfully accomplished without this step (preliminary mixing, watering, and curing). This construction step is necessary only when highly plastic clays are stabilized. The first application of lime will make the soil more workable, and the final mixing and pulverization will be more efficient.

c. Add water, if necessary, during the mixing and pulverization process.

50. Compaction.

a. Begin compaction immediately after final mixing.

b. Use pneumatic-tired or sheepsfoot rollers.

51. Final curing.

a. Let cure for 3 to 7 days.

b. Keep surface moist by applying water or an asphaltic membrane.

Cement stabilization

52. Preparation.

a. Shape surface to crown and grade.

b. Scarify, pulverize, and prewet soil, if necessary. All deleterious material such as stumps, roots, turf, etc., should be removed.

c. Reshape to crown and grade.

53. Cement spreading. Use one of the following methods:

a. Spot bags of cement on the runway, empty the bags, and level the cement by rake or drag.

b. Apply bulk cement from self-unloading trucks (bulk trucks) or dump trucks with spreaders.

54. Mixing.

a. Add water (see paragraph 74) and mix with either a single-shaft mixer or a multiple-shaft mixer.

b. Mixing can be performed by processing in 6- to 8-ft-wide passes (width of mixer) or by mixing in a windrow.

c. Continue mixing and pulverizing until all of the soil-cement mixture will pass a 1-in. screen and at least 80 percent will pass a No. 4 sieve, exclusive of any gravel or stone.

55. Compaction.

a. Begin compaction immediately after final mixing, otherwise cement may hydrate before compaction is completed.

b. Use pneumatic-tired and sheepsfoot rollers; finish surface with steel-wheeled rollers.

56. Curing. Apply a bituminous material at a rate of approximately 0.15 to 0.30 gal per square yard. Curing may also be accomplished by covering with about 2 in. of soil or thoroughly wetted straw.

Bituminous stabilization

57. In-place stabilization using bituminous materials can be performed with a traveling plant mixer, a rotary-type mixer, or a blade. The methods for using these mixers are outlined below:

a. Traveling plant mixer.

(1) Preparation of roadbed: The roadbed on which the mixed material is to be blaced must be shaped and compacted. A prime coat should be applied on the roadbed and allowed to cure. Excess asphalt from the prime coat should be blotted with a light application of dry sand.

(2) Aggregate preparation: The aggregate is usually hauled to the job and windrowed by hauling trucks, spreader box, or blade.

(3) Adding asphalt: Asphalt is added to the windrow by an asphalt distributor truck or within the traveling plant mixer.

(4) Mixing: Several types of single- or multiple-pass shaft mixers are available.

(5) Aeration: Work the material until about 50 percent of the volatiles have escaped; a blade is often used for this operation.

(6) Spread to uniform grade and cross section.

(7) Compact.

b. Rotary mixer.

(1) Prepare the roadbed as explained above for the traveling plant mixer.

(2) Spread aggregate to uniform grade and cross section.

(3) Mix the aggregate by one or more passes of the mixer.

(4) Add asphalt in increments of about 0.5 gal per square yard and mix. Asphalt can be added within the mixer or with a distributor truck.

(5) Make one or more passes of the mixer after each addition of asphalt.

(6) Maintain the surface to grade and cross section by using a blade during the mixing operation.

(7) Aerate the mixture.

c. Blade mixing.

(1) Prepare the roadbed as explained above for the traveling plant mixer.

(2) Place the material in a windrow.

(3) Apply asphalt to flattened windrow with a distributor truck; it is best to use a multiple application of asphalt.

(4) Mix thoroughly with a blade.

(5) Aerate the mix.

(6) Move the mixed windrow to one side of the roadway.

(7) Spread the mixture to proper grade and crown.

(8) Compact the mixture.

Central-plant construction methods

58. Although central-plant mixing is desirable in terms of the overall quality of the stabilized soil, it is not often used for TO construction. Stabilization with asphalt cement, however, must be accomplished with a central hot-mix plant. The construction methods for central-plant mixing that are common for use with all types of stabilizers are given below:

a. Materials storage areas.

(1) Prepare storage areas for soils and aggregates.

(2) Prepare storage area for stabilizer.

(3) Prepare storage area for water.

b. Mixing (Figure 14).

(1) Prepare area to receive materials.

(2) Prepare mixing areas.

c. Hauling. Accomplish using trucks.

d. Placing (Figure 15). Use a spreader box or bottom-dump truck followed by a blade to spread to a uniform thickness.

e. Compaction. Use steel-wheeled, pneumatic-tired, or sheepsfoot rollers, depending on the material.

f. Curing. Provide an asphaltic membrane for cement-stabilized soil and an asphaltic membrane or water for lime-stabilized soils.

Surface waterproofing

59. Preparation.

a. Shape area to crown and grade.

b. Remove all deleterious materials such as stumps, roots, turf, etc., and sharp-edged, soil-aggregate particles.

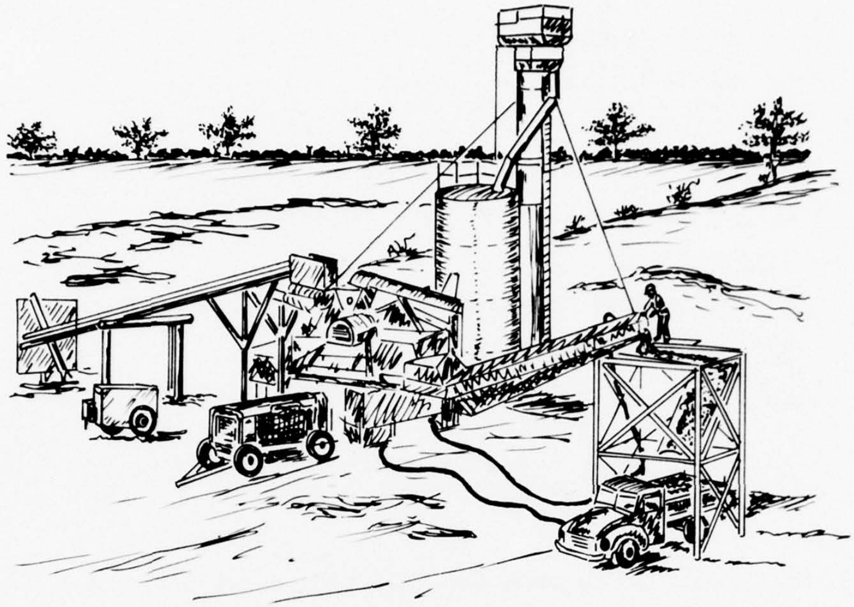

Figure 14. Central-plant mixing

Figure 15. Placing of central-plant-mixed stabilized soil with spreader box

60. Mixing.

a. Adjust water content to about optimum to 2 percent below optimum and mix with a traveling mixer, pulvimixer, blade, scarifier, or plow.

b. Blade to grade and crown.

61. Compaction.

a. Begin compaction after mixing.

b. Use pneumatic-tired or sheepsfoot rollers.

62. Membrane placement.

a. Grade area to grade and crown and cut anchor ditches.

b. Use motor grader.

c. Roll area with a steel-wheeled roller or a lightweight pneumatic-tired roller.

d. Place neoprene-coated nylon fabric or polypropylene-asphalt membrane.*,**,†

MESL

63. Details of procedures for MESL-type construction are available in Instruction Reports S-71-1* and S-69-5.**

Construction Hints

64. The difference between a good stabilization job and a poor one is often a matter of a few seemingly minor details. Some of these have been discussed previously, but they are mentioned again below along with others which should assist the engineer in accomplishing a satisfactory job.

Preparation of roadway

65. Shaping the roadway to proper crown and grade before construction starts is particularly important if the in-place soil is to be used. There will be little displacement of the soil during

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* Joseph and Webster, op. cit.

** Burns and Brabston, op. cit.

† S. G. Tucker and R. H. Grau, "Description, Placement, Maintenance, and Recovery Instructions for XW18 Membrane," Instruction Report S-70-4, Jun 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

processing, so the grade at the beginning of construction will largely determine the final grade.

66. When borrow soil is used for stabilization, it should be placed on a well-compacted and accurately graded subgrade. If the subgrade is not properly compacted, it will be impossible to obtain adequate compaction in the overlying stabilized material, resulting in low stabilized soil strengths. Also, if the subgrade is not at proper grade, the stabilized layer will not have a uniform thickness.

67. When other equipment is not available, the roadway can be scarified and pulverized using agricultural equipment (discs, plows, etc.). However, this equipment is often underpowered for this type of construction. The use of several additional passes may help, or thin lifts can be scarified and moved to the side of the road until the desired depth is pulverized. Proper equipment is necessary for rapid, efficient pulverization, but proper moisture content is also necessary. If dry and brittle soils are difficult to pulverize, they can often be broken down by first adding water and allowing it to soak in.

68. During roadway preparation, it is important that adequate drainage be provided at *all times*. *Thirty minutes devoted to insuring* adequate drainage rather than ponding may save days of construction and operating time if rain occurs.

Distributing stabilizer

69. Although bulk distribution or distribution of the stabilizer in the mixing equipment gives the best results, spreading of bagged lime and cement can be accomplished satisfactorily provided adequate labor is available. Bags should be spotted transversely and longitudinally at regular, predetermined intervals. When the bags are opened, the contents should be dumped to form transverse windrows, which are then spread longitudinally by a harrow or drag or similar equipment.

70. Stabilizer spreading on windy days can be dangerous if caustic materials are used. Distribution of lime in the slurry form should be encouraged to prevent lime from blowing; however, slurry distribution cannot be accomplished if a wet soil is encountered.

Mixing

71. A uniform mixture of the stabilizer, soil, and water is extremely important. Improper mixing can often be spotted by checking at regular intervals before compaction to inspect the color of the soil-cement mixture in trenches or holes carried to the full depth of the treatment. A uniform texture and color from top to bottom indicates a well-mixed material. Streaks indicate improper mixing.

72. Mixing can be accomplished with agricultural equipment such as plows and discs, but this type of construction takes more time than that with a proper stabilization mixer. Thin lifts and/or numerous passes of the equipment may be necessary.

73. When the depth of lime stabilization is 12 in. or more, a new technique termed "deep plow lime stabilization" may be used. As shown in Figure 16, a large plow which will penetrate to 24 in. or more is used to turn the soil over and distribute the lime to the depth of plowing. When the lime reacts on the soil to reduce its plasticity and increase its workability, the mixing becomes more efficient although probably not as good as the same operation with proper stabilization equipment. For this reason, the upper portion of the layer is usually mixed and compacted with more conventional equipment. However, this method can save considerable time and effort when greater depths must be stabilized.

74. It is always important to maintain adequate water in soil-lime and soil-cement mixtures. Usually, at least 2 percent additional water is needed for the dry stabilizer alone, and more water may be needed if the stabilizer increases the optimum moisture content of the soil, as often happens with lime.

75. With cement-stabilized soils, it is important that any soil mixed be compacted during the same day. If allowed to remain overnight, the soil-cement will set up and be impossible to work or compact the next day.

Compaction

76. Compaction equipment should be selected to match the soil type and the type of stabilizer. Sheepsfoot and pneumatic-tired rollers are often used when lime or cement stabilization is used.

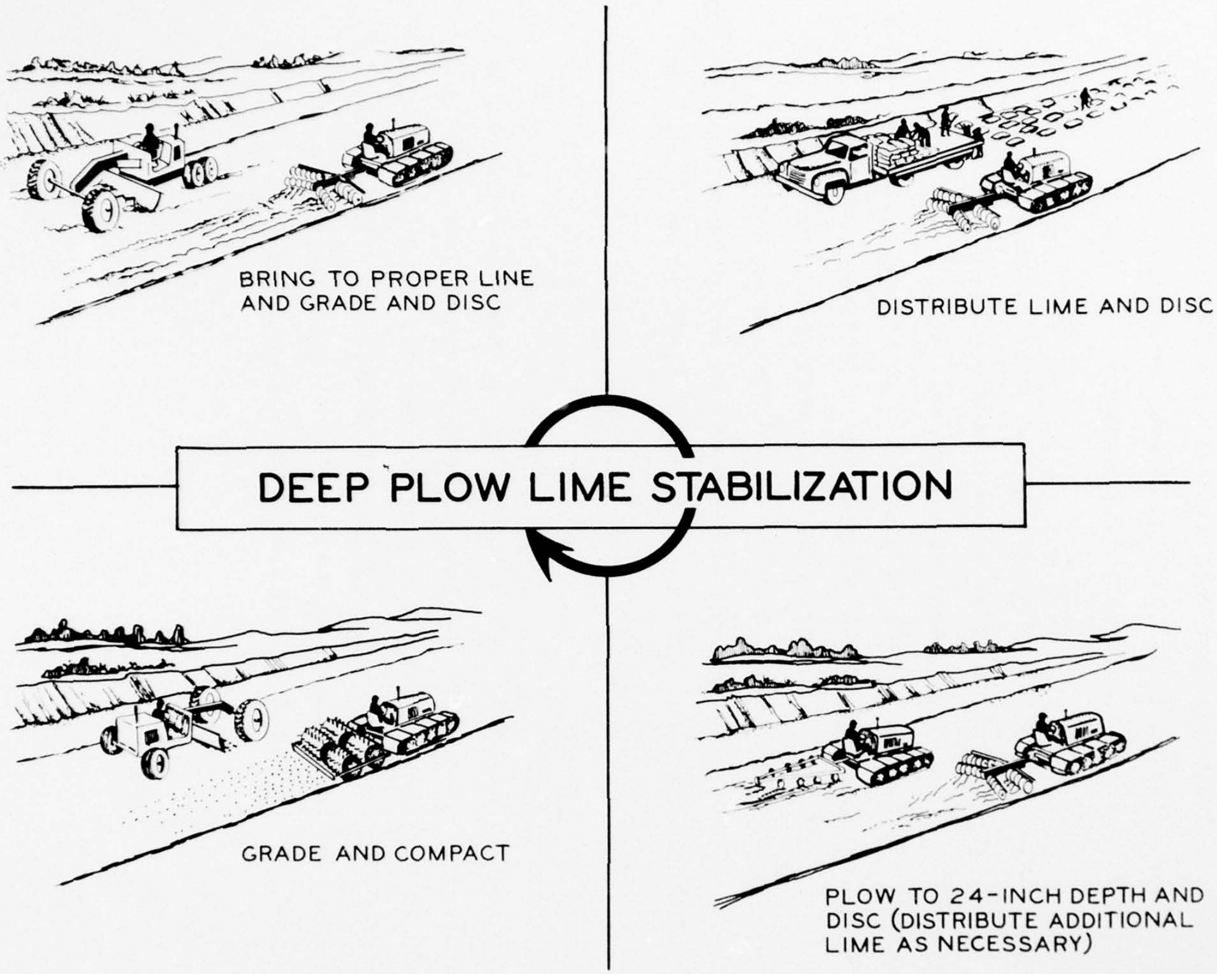

Figure 16. Deep plow lime stabilization

AD-A047 630 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 13/13
PROCEDURE FOR UPGRADING DETERIORATED THEATHER OF OPERATIONS (TO--ETC(U)
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Pneumatic-tired or steel-wheeled rollers are often used with bituminous stabilization. Steel-wheeled rollers can be used effectively to smooth the base course prior to placing the surfacing material.

77. If more than 8 to 12 passes of a particular compactor are necessary to achieve adequate density, one or a combination of the following should be changed: lift thickness, weight of compactor, unit pressure, water content, or type of compactor.

Curing

78. Adequate curing is necessary for proper strength gain of lime- and cement-stabilized soil. The curing operation should be performed so that the moisture content of the soil at the time of compaction is maintained. The application of a bituminous membrane offers the best solution; however, watering can be effective provided a nearly uniform water content is maintained. This requires frequent watering since wetting and drying are harmful to the stabilized soil.

79. If a bituminous membrane is used, it should be applied to the moist stabilized surface. The surface should first be swept clean of dry, loose, and extraneous material.

Preliminary mixing, watering, and curing

80. Preliminary mixing, watering, and curing are important if lime stabilization is used in certain types of soils. The addition of lime and the subsequent initial curing period will aid in later mixing operations. After preliminary mixing and watering, the lime-stabilized soil should be shaped and compacted lightly to minimize evaporation loss, lime carbonation, or excessive wetting from rainfall.

Table 1

Cement Requirements for Various Soils

USCS Group	Usual Range in Cement Requirements* Percent by Volume	Percent by Weight	Estimated Cement Content and That Used in Moisture-Density Test Percent by Weight	Cement Contents for Wet-Dry and Freeze-Thaw Tests Percent by Weight
GW, GP, GM, SW, SP, SM	5 to 7	3 to 5	5	3 to 7
GM, GP, SM, SP	7 to 9	5 to 8	6	4 to 8
GM, GC, SM, SC	7 to 10	5 to 9	7	5 to 9
SP	8 to 12	7 to 11	9	7 to 11
CL, ML	8 to 12	7 to 12	10	8 to 12
ML, MH, OH	8 to 12	8 to 13	10	8 to 12
CL, CH	10 to 14	9 to 15	12	10 to 14
OH, MH, CH	10 to 14	10 to 16	13	11 to 15

* For most "A" horizon soils, the cement should be increased 4 percentage points if the soil is dark gray to gray and 6 percentage points if the soil is black.

Table 2

Selection of Type of Emulsified Asphalt For Stabilization

Percent Passing No. 200 Sieve	Relative Water Content of Soil	
	Wet (5 percent +)	Dry (0 to 5 percent)
0 to 5	SS-1h (or SS-Kh)	SM-K (or SS-1h*)
5 to 15	SS-1, SS-1h (or SS-K, SS-Kh)	SM-K (or SS-1h,* SS-1*)
15 to 25	SS-1 (or SS-K)	SM-K

* Soil should be prewetted with water before using these types of emulsified asphalts.

Table 3

Determination of Quantity of Emulsified Asphalt

Percent Passing No. 200 Sieve	Pounds of Emulsified Asphalt per 100 lb of Dry Aggregate When Percent Passing No. 10 Sieve is:					
	50*	60	70	80	90	100
0	6.0	6.3	6.5	6.7	7.0	7.2
2	6.3	6.5	6.7	7.0	7.2	7.5
4	6.5	6.7	7.0	7.2	7.5	7.7
6	6.7	7.0	7.2	7.5	7.7	7.9
8	7.0	7.2	7.5	7.7	7.9	8.2
10	7.2	7.5	7.7	7.9	8.2	8.4
12	7.5	7.7	7.9	8.2	8.4	8.6
14	7.2	7.5	7.7	7.9	8.2	8.4
16	7.0	7.2	7.5	7.7	7.9	8.2
18	6.7	7.0	7.2	7.5	7.7	7.9
20	6.5	6.7	7.0	7.2	7.5	7.7
22	6.3	6.5	6.7	7.0	7.2	7.5
24	6.0	6.3	6.5	6.7	7.0	7.2
25	6.2	6.4	6.6	6.9	7.1	7.3

* 50 percent or less.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Burns, Cecil Dawson
Procedure for upgrading deteriorated theater of operations (TO) pavement facilities / by Cecil D. Burns. Vicksburg, Miss. : U. S. Waterways Experiment Station, 1977.
37, [56] p. : ill. ; 27 cm. (Instruction report - U. S. Army Engineer Waterways Experiment Station ; S-77-3)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.
References: p. 36-37.

1. Airfield maintenance. 2. Flexible pavement maintenance. 3. Maintenance. 4. Military facilities. 5. Military roads. 6. Pavement deterioration. 7. Pavements. 8. Rigid pavement maintenance. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Instruction report ; S-77-3.
TA7.W34i no.S-77-3